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Women in Astronomy in the United States 1875-1920

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Fig. 1. Annie Jump Cannon (Annals of the Harvard College Observatory vol. 112, frontispiece)

WOMEN IN ASTRONOMY IN THE UNITED STATES 1875-1920

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CHAPTER I

INTRODUCTION

In the period from about 1875 to 1920 (the dates are only intended to be approximate) more than 164[1] women held astronomical jobs in the United States, and a few became famous for important scientific contributions. This seems surprising at first, because it is not a period in which many opportunities were open to women, particularly for intellectual pursuits. This thesis will examine the development of a role for women in astronomy and the reasons for the acceptance of women into this field. The goal is to show how the scientific work done by the women astronomers was affected by the limitations of the opportunites open to them.

The position of women in astronomy in this period has not been previously studied in depth except for a few individuals and institutions. I first came to this topic out of curiosity about the few famous women who are mentioned in elementary astronomy courses and textbooks. I was interested in where these women came from, and whether they were isolated exceptions or the most visible part of a larger trend. The trend has in fact turned out to be larger than I ever expected. Women filled a significant place in astronomy in the United States by the early

twentieth century, and the body of this thesis is devoted to tracing the development and nature of this role, of showing the position of ordinary women astronomers from which the famous women came. It is a situation that seems anomalous, and I wanted to find out why it arose.

There are two reasons to discuss the position of women in science. The first is that they have often been given less historical attention than they deserve. Secondly and more important, the pressures which science puts on members of minority groups within the field and the effects of these pressures on the people involved are things we need to understand today. A study of the acceptance of a new group of participants, such as women, into science can elucidate the social structure of science and the ways in which this structure influences the scientific work being done. The question of the way science treats minority groups cannot be answered generally from one case, but it lies behind the analysis of the development of the position of women in astronomy given in the last chapter.

There is much that could not be done within the scope of this thesis. I undertook archival research at Harvard and many of the older women's colleges, surveyed the astronomical journals for papers by women, and interviewed some women who were at Harvard in the 1920s (and one who started work at Harvard in 1906) and who remember the women who were there earlier. Because of the limitations of time

I could not carry out archival research on the position of the less famous men astronomers as would be necessary for detailed conclusions about how the position of women was different from that of men. It also proved impossible, because of lack of published material on women in other sciences, to find out much about how the positions of women varied from one science to another. Most of my material is historical; it is only a small part of what should be a larger study. More comparative work is necessary in order to draw conclusions about why women received a certain sort of treatment and what this reveals about science. Because of these limitations the conclusions that I can draw are only tentative, but I hope they will serve as suggestions for future research.

A role for women in astronomy in the United States developed through the interaction of a number of institutions. In order to spare the reader confusion and to keep the length reasonable, certain institutions, most notably Vassar and Harvard, will be taken as examples of the development of a position for women in astronomy and discussed in detail. Others, whose histories are interesting but similar, will only be summarized in the discussion of women's careers and the scientific work of the women's colleges. This is followed by a discussion of the four women at Harvard who became famous and a general analysis with tentative conclusions. The purpose of this thesis is not to give

a complete history of women in astronomy in this period, but rather to study the institutional and social roots of the historical developments.

The Situation of Astronomy

In order to understand the history of the women astronomers it is important to remember that professional astronomy had only recently been established in America. The first permanent observatory in the United States was established in 1838 by Albert Hopkins at Williams College. The first observatories capable of competing with those in Europe were Harvard College Observatory, founded in 1839, the Naval Observatory, founded in about 1842, and the Cincinnati Observatory, founded in 1843. Even these institutions did not always pursue original astronomical research; the Cincinnati Observatory suffered from disagreements between the trustees and the director, and Congress demanded that the Naval Observatory do only research related to navigation. Small observatories grew up quickly at various colleges, but when women first entered astronomy in the 1870s, astronomical work in the United States had not yet caught up with that being done in Europe.

The first development to change the balance of power in astronomy in the late nineteenth century was photography. The first photograph of a star was a daguerreotype taken in 1850 at Harvard College Observatory while William Cranch Bond was the director.[2] It was not until the

development of dry plates (because a wet plate cannot be kept wet for the necessary long exposures), though, that photography became useful to astronomy. Soon photographic plates were being taken in large numbers, particularly at Harvard, and they were available as a permanent record which could be observed and compared at leisure. This influenced the kind of astronomical work being done because this was most helpful for the study of large numbers of faint objects, such as unusual stars and nebulae.

The second major trend in institutions and instruments in this period was the development of large observatories supported by private philanthropy. New and larger telescopes were built at a rapid rate because of the support of rich benefactors who each wanted to give the largest telescope in the world. This resulted in the 36-inch refractor at Lick Observatory in 1889, the 40-inch refractor at Yerkes Observatory in 1897, and the 60-inch and 100-inch reflectors at Mount Wilson in 1908 and 1917.[3] These telescopes brought the United States to leadership in observational astronomy. They stimulated an interest in the size and structure of the universe, because they could see fainter and more distant objects than ever before. Work on these topics resulted in the better understanding of the size of our galaxy and the nature of the spiral nebulae which was developed in the 1920s.

All these observatories were of semi-independent status. Cincinnati Observatory was funded by public subscription, the Naval Observatory mostly by Congress (giving it less independence). The staff of Harvard College Observatory had no teaching responsibility, despite its connection to the university, and graduate students were not accepted until the 1920s. Yerkes was similarly attached to the University of Chicago. The Carnegie Foundation supported Mount Wilson, so it was independent of any university. Because observatories were not yet closely connected with universities the academic status of astronomy was uncertain. Many astronomers (Simon Newcomb, for example) were mostly self-educated, and even the young and rising astronomers in the late nineteenth century learned physics and mathematics in colleges but learned astronomy by working as assistants in observatories.

The scientific state of astronomy reflected this recent transition to professional status, which had happened only a few decades earlier in Europe. Amateur astronomers had concentrated on individual interesting objects; professional astronomers had the resources to undertake the massive compilations of data that were increasingly necessary. One of the major research projects of most observatories in the third quarter of the nineteenth century was determining star positions. In the last quarter of the nineteenth century a new sort of astronomy grew up, astrophysics. Using

the spectroscope as a tool, astronomers studied the spectra of stars. Mount Wilson particularly became a center for work on the solar spectrum and the features of the sun. This work bore fruit in the early twentieth century when the development of quantum mechanics began to allow a physical understanding of the observed spectra.

The Position of Women

The position of women in late nineteenth and early twentieth century America is a subject that is just beginning to be studied. During the 1880s and 1890s the feminist movement, which had been fighting for suffrage for women since 1848,[4] became more widespread, but little was actually accomplished. Part of the reason for the increase in the number of women seeking careers was that the death of so many men during the civil war increased the number of unmarried women who had to work to support themselves.[5] The ideological base of the feminist movement of the late nineteenth century was a revolt against the Victorian image of women as ideal passive creatures. The feminists asserted (but most people still disagreed) that women were capable of intellectual pursuits and should take an active role in political and social issues. It should be remembered that women did not even get the right to vote in the United States until 1920.

Considerable controversy surrounded the subject of higher education for women during this period. Public

education became widespread during the nineteenth century and women began to fill the teaching jobs. The first academically rigorous women's college, Vassar, was founded in 1865. It seemed desirable to have better educated teachers, particularly as women began to be allowed to teach high school, and upper- and upper-middle-class women increasingly demanded education. People raised serious arguments about the effect of education of women's health and reproductive ability, but as the first women with college degrees married and had children, education became more and more acceptable for women. The women's colleges sought to give women the same education that men got, so the emphasis was on the classics. Science was not ignored, however, and in fact women's colleges were often leaders in the introduction of new methods of teaching science. The growing number of qualified college graduates put pressure on the graduate and professional schools to admit women, and in the last decade of the nineteenth century and the early twentieth century opportunities for advanced study opened up in considerable numbers, but not without a fight. By the 1920s women were firmly established in graduate study, and in fact a higher percentage of all Ph.D.'s were given to women in the decade 1920-29 than in the decade 1960-69.[6]

CHAPTER II

THE DEVELOPMENT OF A PLACE FOR WOMEN IN ASTRONOMY: VASSAR

Maria Mitchell, the first director of the Vassar College Observatory, created the earliest opportunities for women to study astronomy on a level which would prepare them for professional careers. Maria Mitchell had discovered a comet in 1847, thus becoming America's first famous woman astronomer. When Vassar College was founded in 1865 she became professor of astronomy, and set up a program of rigorous astronomical training and commitment to research which served as a model for the other women's colleges. The development of the program at Vassar is typical of the women's colleges: from early equipment problems, to growing numbers of students which convinced the administration to improve the equipment but resulted in a teaching load that left little time for research, to the hiring of additional faculty and a new commitment to original research. Vassar also provides an example of the growth of ties between the women's colleges and the large observatories that allowed the women's colleges to place their graduates in astronomical jobs.

In 1847, Maria Mitchell, the 29 year-old librarian of the Nantucket Atheneum, discovered a comet. She had learned astronomy from her father, a noted amateur, had studied extensively on her own from books, and was an able and dedicated observer. Her father sent word (a few days later because of a storm which delayed the mail from the island) of her discovery to his friend William Bond, the director of Harvard College Observatory, who confirmed it and sent a report to the president of Harvard, Edward Everett. It happened that the King of Denmark offered a gold medal for the first discovery of a telescopic comet. The committee decided initially to give the award to Father Francesco de Vico of Rome, who had discovered the same comet two days later (transatlantic mail was so slow that the decision was made before the news of Mitchell's discovery arrived). But, as Jones and Boyd wrote: "President Everett, who believed that George Bond had been unjustly deprived of the medal in 1846, determined that an American astronomer should not be outdone a second time."[7] After some diplomatic wrangling, Mitchell received the prize that made her famous.

The combination of this honor and her father's personal connections enabled her to find professional employment. Her position as a dutiful unmarried daughter taking care of her aging father made it necessary for her to continue to work. A friend of hers, Commander Charles H.

Fig. 2. Maria Michell at her telescope in Nantucket, from a painting by Hermione Dassel (1851), Jones and Boyd, The Harvard College Observatory, p. 384.

Davis, hired her as a computer (one who does computations) for the Coast Survey in 1849, at a salary of $300 a year. She worked at home computing tables of the positions of planets (because she was a woman she was assigned Venus) for the American Ephemeris and Nautical Almanac, an annual compilation of astronomical tables for mariners.[8] In 1865 the founder of Vassar College, Matthew Vassar, as part of his attempt to involve the foremost American women scholars in the first women's college that sought to be of comparable quality to the best men's colleges (an attempt which was questioned by a number of trustees who did not approve of women professors), invited Maria Mitchell to be professor of astronomy and director of the observatory. He promised her an observatory equipped for research and a house for herself and her father. Maria Mitchell accepted the position, and she and her father lived and worked there until his death in 1869 and her retirement in 1888.

Vassar supplied Maria Mitchell with equipment that should have been sufficient for worthwhile scientific research. When minor problems arose, however, the college was reluctant to spend the money to solve them. With a 12-inch objective lens, the equatorial telescope was one of the largest in the United States in 1865, but the objective was of poor quality. Mitchell wrote:

> After nearly three years I have come to the conclusion, that the telescope's illuminating power is good; its defining power bad. It picks up minute points of light

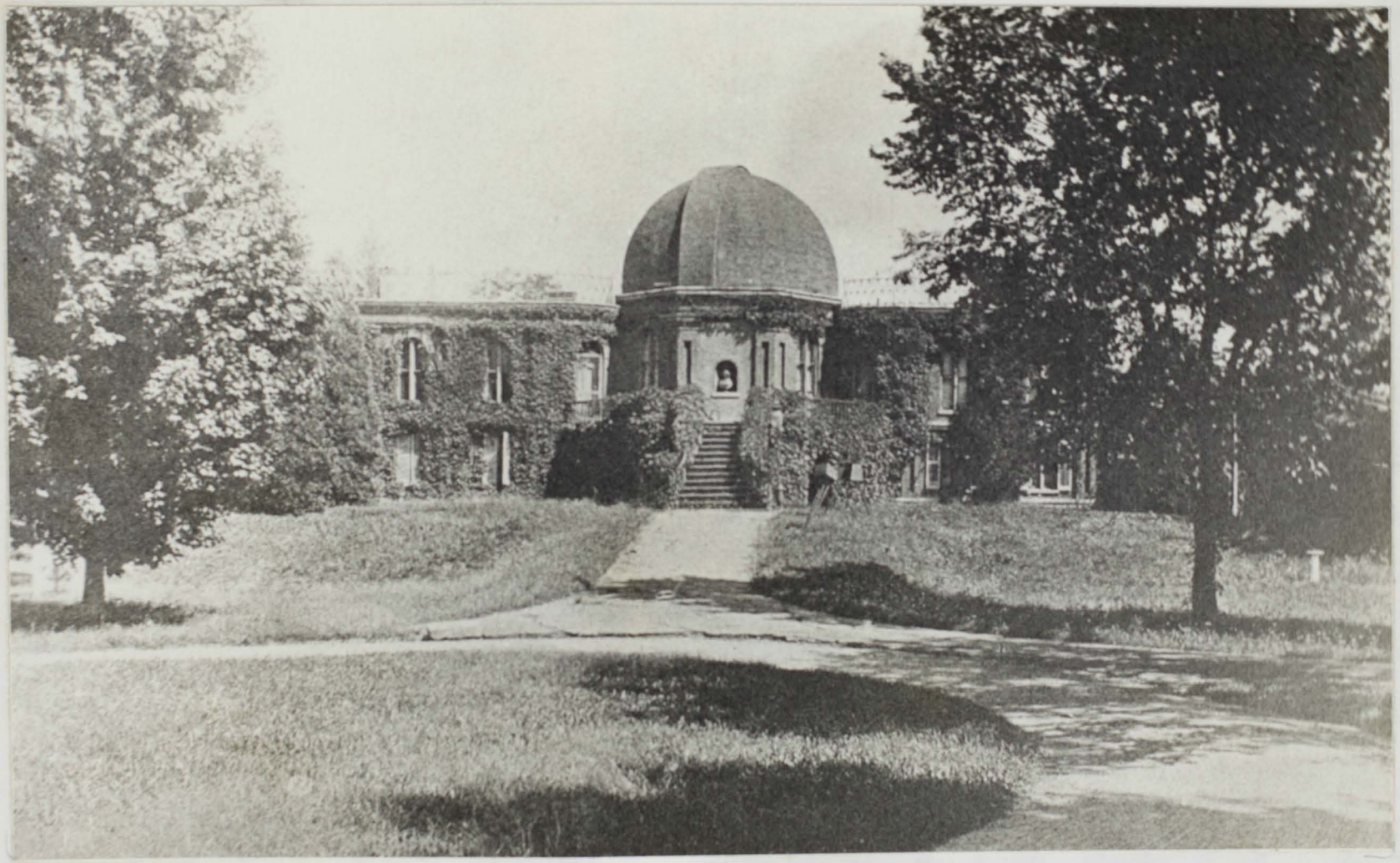

Fig. 3. Vassar College Observatory (Popular Astronomy 30 (1922): facing p. 604).

> very well; it does not give them a sharp outline.... It is exceedingly trying to an observer, to have in charge a telescope ranking as fourth or fifth in the country, and to be unable to compete with those of much less aperature.[9]

Alvin Clark and Sons (the most famous telescope maker in the country and possibly the best in the world at that time) refigured the objective in 1868, and in her next annual report Mitchell proudly claimed that the telescope ranked third in the country, exceeded only by those in Chicago and Cambridge.[10] This problem solved, however, difficulties arose with the mounting of the telescope. An inadequate mounting made the comet and asteroid position work, which later became the major research interest of the women's colleges, impossible, so Mitchell concentrated on observations of the surface features of Jupiter and Saturn. These were published in Sillimans Journal and the American Journal of Science. She finally persuaded the college to provide the money to have the mounting rebuilt in 1887.[11]

Despite these problems Maria Mitchell gave her students training and inspiration to become professional astronomers. A gifted teacher, she encouraged her students to question what they were taught and learn for themselves.[12] Brought up a Quaker and deeply involved in the women's movement (in fact she was president of the fourth Women's Congress in 1876 in Philadelphia), she wrote: "I consider it one of my duties to the young women who come into my

department to encourage a respect for remunerative occupation. Why should girls be brought up with an idea that paid labor is ignoble?"[13] A letter from one of her students to another shows that she communicated these beliefs to students and made them want to seek astronomical careers even though they were discouraged by attitudes towards women in the outside world. In 1870 Gertrude Mead, studying for her M.A. at Vassar, wrote to Mary Whitney, who later became Mitchell's successor:

> You think I am brave. Well, if I am, what are you? To be sure I am back here alone, but then I have Miss Mitchell and all these grand instruments, and nobody makes fun of it all here. But when I get home, no one there will take any interest in Astronomy. I shall have no telescope at first, and there will be no one there to help me on. Do you think I shall be brave enough then to hold on tight to what I have begun? When I think of it so, I get discouraged. Presently I think of it this way. There you have been away from the college two years. You have your telescope, and have commenced work, and now you have even gone out to Safford.[14] If you have held out, why shouldn't I? Then I feel better.... I believe in you thoroughly, and that is what I don't in many. You said last commencement day, "It is worth working for." I believed you, and I shall always cling to that sentence.... Will you help me to hold on, and take an interest in what I do in it? I never expect to accomplish much. I have thought it all over, and don't think I care at all to get fame. I want to work at it because I love it, and because it is so much better to have a purpose to live for than to have nothing.[15]

Two of Maria Mitchell's students, Mary Whitney and Antonia Maury, went on to become notable astronomers, and a number of her students became professionals in other fields.

Maria Mitchell trained Mary Whitney as her successor. Whitney graduated from Vassar in 1868 and received her M.A.

Fig. 4. The Hexagon, senior astronomy class at Vassar College in 1868. Mary Whitney is seated at the table (Popular Astronomy 30 (1922): 599).

from Vassar in 1872. She studied at Harvard in 1869-70 and 1872. Maria Mitchell persuaded the famous Harvard mathematician Professor Benjamin Peirce to invite Whitney to attend as his guest first his lectures on Quaternions and then his senior course of celestial mechanics (her fellow students in the latter were William Byerly and James Mill Peirce, both of whom became Harvard professors).[16] Whitney taught high school in Massachusetts in 1872-74. In 1874, when her sister went to Zurich to study medicine (because there was little opportunity for women to study medicine in the United States), Mary Whitney accompanied her, and studied mathematics there for two years. In 1881 she became Maria Mitchell's assistant, and in 1888, when Mitchell retired, she became professor of astronomy and director of the Vassar College Observatory.

Despite a heavy teaching load, Whitney pursued some original research. By 1906-7 there were eight different astronomy courses given, with a total of 160 students.[17] Whitney hired with her own funds an assistant, Caroline Furness, who helped with the teaching and research from 1894 to 1910, and later succeeded Whitney as professor of astronomy. In an annual report Whitney described their schedule: a graduate student "observes every evening when the telescopes are not in use by undergraduates. Frequently, when clear evenings have been few, she uses the glass up to 10 o'clock; then Miss Furness and I begin our special work,

and carry it on to 1 or 2 am."[18] In addition to visual research, the equipment was upgraded, sometime in the 1890s, by the purchase of a Repsold machine for making accurate measurements of stars on photographic plates, which allowed research on plates borrowed from other observatories (the equatorial at Vassar was not suited for photographic work).[19] Whitney published many papers in the astronomical journals, sometimes with Furness or a graduate student, on comets, asteroids, and variable stars. This work will be discussed further when the scientific work of the women's colleges is considered.

Most significant for the development of an institutional position for women in astronomy, however, was not the scientific work done at the women's colleges, because they employed so few women, but the development of connections with the large observatories that enabled the women's colleges to place their graduates in jobs. As will be discussed later the large observatories started to employ women in the 1880s and 1890s. The women did the routine computation and measurement of photographic plates that became increasingly necessary as astronomy became more mathematical and more dependent on photography. Vassar was particularly successful in placing its graduates in this sort of work; alumnae records show that of 21 women mentioned in the records of the astronomy department who pursued astronomical work after graduation, nine worked

for three years or more at an observatory not connected with a women's college (compared with two of a similar group of 14 Smith graduates).[20] Five Vassar women worked at least briefly at Mt. Wilson, two at Yerkes, three at Harvard, three at Columbia, and one each at Allegheny, Lick, Yale, and the Naval Observatory.

The basis of these institutional connections was personal friendships. Cooperation between Vassar and Columbia started in 1896 when Prof. Harold Jacoby suggested that Caroline Furness make a detailed study of some plates of the region around the north pole.[21] Furness got her Ph.D. from Columbia in 1900 for this work. Yerkes accepted women for positions as volunteer summer assistants, and Furness worked there under Hale in 1900. The friends she made there were useful; in 1903 Frank Schlesinger wrote her that she should encourage one of her students to apply to Professor Hale for a job at Yerkes as a computer on parallax work supported by the Carnegie Foundation. He added that conditions for boarding had improved since Furness's stay.[22] The connection with Mount Wilson was established when Hale left Yerkes to be the first director of Mount Wilson.

Letters from these various observatories show that they looked to Vassar when they wanted to hire women. George E. Hale, then at Yerkes, wrote to Mary Whitney in 1901 to ask: "Can you recommend any young women for work

here in measuring and computing?"[23] Simon Newcomb of the Naval Observatory wrote in 1905: "I now have work for one or two good computers; if you have any that you can recommend for intelligence, accuracy and speed I should be very much pleased."[24] An engineer from the American Telephone and Telegraph Company, inquiring if Vassar graduates were trained for and interested in the sort of computing he needed done, wrote: "Last winter, in talking with Mr. Walter S. Adams about the work at the Mount Wilson Solar Observatory, he said that a large part of the computing was done by Vassar graduates who had received their training in your department of Astronomy which had especially fitted them for such work."[25]

The development of the astronomy department at Vassar illustrates the growth of a role for women in astronomy. At Vassar women could obtain the education they needed to become astronomers. They also found a career structure; their education prepared them for particular jobs, even though there may not always have been enough jobs to go around. The personal leadership for the development of this professional structure came from Maria Mitchell and Mary Whitney; much must be attributed to their effort and their belief that women could do scientific work. The astronomy programs at the women's colleges were successful; it was not lack of opportunity for scientific training that prevented women astronomers from doing original scientific work.

CHAPTER III

THE SITUATION OF WOMEN IN OBSERVATORIES: HARVARD

There were two types of careers open to women astronomers: as professors in women's colleges or as assistants in large observatories. Harvard College Observatory will be examined as a case study of the opportunities open to women astronomers at observatories. The other large observatories--the Naval Observatory, Yerkes, Columbia, Mt. Wilson--also hired women assistants. But Harvard hired women first and employed the largest number of women, so it probably served as an example for the others. The women astronomers who made the largest scientific contributions worked at Harvard. Women were hired as computers to do the routine calculations and make measurements on photographic plates. Most of the women had little scientific training or talent, but those with more ability found some opportunities for creative work open to them. This chapter will look at the women at Harvard as a group, leaving until a later chapter the individual achievements of the women who became famous.

The example Maria Mitchell set at the Coast Survey may have encouraged Harvard to hire women. Maria Mitchell

Fig. 5. Harvard's Women Computers, about 1917. Left to right-- Ida E. Woods, Evelyn F. Leland, Florence Cushman, Grace Brooks, Mary H. Vann, Henrietta Leavitt, Mollie O'Reilly, Edith F. Gill, Alta Carpenter, Annie J. Cannon, Dorothy Block, Arville D. Walker, Frank Hinkey (courtesy of Harvard College Observatory).

received friendship and help from William Bond, the first director of Harvard College Observatory, and his son George, the second director.[26] Perhaps on their advice, since the Coast Survey was based in Cambridge and closely connected with Harvard, Commander Davis hired Mitchell to do computations for the American Ephemeris and Nautical Almanac (a publication of the Coast Survey). When Davis was ordered to sea and Joseph Winlock succeeded him in 1857, Mitchell was still employed by the Coast Survey, though she did her work at home rather than in Cambridge. In 1886 Winlock became the third director of Harvard College Observatory, and held the position until his death in July of 1875. Harvard hired the first three women in that same year, although probably not until after he died. Whether Winlock had planned the hiring of women or someone else proposed it later, it is probable that the example of Maria Mitchell made the idea of hiring women to do computing at Harvard seem reasonable.

At least two of the first three women hired at Harvard had long connections with the observatory and were probably hired because of these connections. Anna Winlock grew up in the Observatory residence while her father was director. Two months after her graduation from high school in 1875 she started work at the observatory, to help support her family after her father's sudden death that June.[27] Mrs. R. T. Rogers, the wife of William A. Rogers, who

supervised the women's work, was also hired sometime in 1875.[28] A special arrangement between William Rogers and Harvard's President Charles W. Eliot resulted in the hiring of the third woman, R. G. Saunders, in November of 1875. On November 23, Rogers wrote President Eliot: "In accordance with your request, I wrote to Miss Saunders, and this morning I have her reply."[29] On November 27, Eliot wrote to Arthur Searle, acting director of the Observatory: "Will you have the kindness to engage Miss Saunders as a computer at the Observatory for one year at a salary of $600 a year."[30]

These three women were hired to reduce meridian circle observations. The meridian circle, a small telescope in a special mounting designed to make accurate measurements of the positions of stars, had been installed in 1870. The Observatory used it in a program of observations of star positions in the zone of the sky assigned to Harvard as part of the international project to revise the Durchmusterung catalogue. The women performed the calculations necessary to reduce the observations to standard coordinates, which involved repetition of a particular formula for each star, using tables of logarithms for multiplication. This was the only work done by women assistants until photography became important.

Credit for Harvard's leadership in opening opportunities to women goes in large measure to Edward Charles Pickering, director of Harvard College Observatory from 1887 until his

Fig. 6. Edward Charles Pickering, Fourth Director of the Harvard College Observatory (courtesy of Harvard College Observatory).

death in 1919. Pickering, a man of good family who had studied physics at the Lawrence Scientific School of Harvard University, held a professorship of physics at MIT when President Eliot invited him to became the director of Harvard College Observatory. A courteous man, he appears to have been sincerely interested in increasing opportunities for women. Margaret Harwood, who worked at the Observatory under Pickering for five years, remembers Pickering's concern and courtesy with the women. When asked why he acted this way she said: "Only because he could get them less expensively. Well, he was like the old-fashioned country gentleman, you might say."[31] A skillful administrator, he no doubt hired women because they were cheaper and more patient with the work he wanted done. But he took pride in his women, and he encouraged other women astronomers by advising the professors at the women's colleges, encouraging amateurs, and founding a fellowship in 1916 for women to study at the Harvard Observatory.

In the next ten years the number of women at the Observatory grew slowly. Pickering next hired Selina Cranch Bond, daughter of the first directory of the Observatory and sister of the second. She needed work because the money left to her by her father had been mismanaged, and she sent Pickering many letters asking for employment before he hired her in 1879. In one letter she wrote:

1038 Tenth St.
Lowell July 5 / 77

Professor Pickering
Dear Sir:

In hope that my effort may be successful I venture to ask if there is at the Observatory any writing about which you would be willing to employ a lady who has had some experience in such work. In previous years, when my father and brother were in charge of the Observatory I often assisted in the copying and simple computations. Being now in need of occupation I should esteem it a great favor could you give me similar writing.

It is with reluctance that I thus address you but trust that as daughter of him who devoted the best of his life and all that he had to the establishment of the Observatory my request will not be considered wholly obtrusive.

I am
Very Respectfully Yours
Selina Cranch Bond[32]

Pickering hired only one more woman before 1885, Nettie A. Farrar, hired in 1881. All of these women remained at Harvard at least until 1885.

The year 1886 brought the founding of the Henry Draper Memorial, which resulted in a major growth of opportunities for women at Harvard. Henry Draper, a wealthy New York doctor who spent most of his time doing astronomical work, had taken the first photograph of the spectrum of a star in 1872 (spectra had been observed visually for many years but never before photographed). When he died in 1882 his widow, who had always served as his assistant, attempted to carry on his astronomical investigations with the cooperation of Pickering. This proved impossible, however, so in 1886 she agreed to support research at Harvard which would continue her husband's work.[33]

The women employed for the Draper Memorial measured objective prism plates. Henry Draper's photographs of stellar spectra were made with a spectroscope attached to the telescope, allowing him to make large photographs of the spectrum of a single star. For the first Draper Memorial catalogue, however, Pickering decided to use a prism placed in front of the objective lens of the telescope (an older method) to produce a photograph showing many stars, each spread out to form a spectrum, on a single plate. The spectra were small, usually less than an inch long, but with a magnifying lens showed sufficient detail for classification. The task of classifying the spectra of each of hundreds of stars on each plate was started by Farrar, continued by Williamina P. Fleming when Farrar left to get married at the end of 1886, and finally completed by Annie Jump Cannon. A contemporary account describes the women's other duties: "In addition to this they record their observations, reduce the coordinates of objects examined, identify the objects photographed with the stars in various catalogues, and finally check the results by a direct comparison of the chart with the photograph."[34] The results of this work will be discussed when the astronomical work done by the famous women at Harvard is considered.

Because of this new line of women's work, amply supported by Anna Draper, and because of Pickering's success in raising money for more assistants to do computing, the

Fig. 7. The Women's Workroom at Harvard. Williamina Fleming is standing, to the left of her in the rear is Antonia Maury, the seated figure in front is Evelyn Leland (Jones and Boyd, The Harvard College Observatory, p. 391).

number of women at Harvard increased rapidly between 1885 and 1900. Twenty-one women were hired between these dates, leaving, when a few retirements are counted in, a staff of 19 women in 1900. There is evidence of the previous training of only eight of these 26 women, but of these only two, Antonia Maury and Annie Cannon (both of whom became famous), had graduated from college. Mabel Stevens took the Radcliffe entrance examinations, but financial circumstances forced her to find employment at the Observatory instead.[35] Annie Masters had previously been a teacher and a bookkeeper,[36] and Florence Cushman had graduated from Charleston High School and worked for a business firm.[37] Desertion by her husband forced Imogen Willis Eddy, a lady of good family, to seek work.[38] When she applied to the observatory she had previous experience in astronomical work, as she had worked for two years for Benjamin A. Gould at the Coast Survey measuring stellar photographs, but she had never studied astronomy.[39]

The backgrounds of these women give evidence of the status and type of duties they were hired for. Few opportunities were open to women except in domestic service or factory work in this period, even women secretaries did not become common until after 1900. Women considered astronomical jobs highly desirable because of good working conditions and comparatively pleasant duties, and it did not require a college education or an upper class background. In a society that confined opportunites for women to a job as a servant or the Lowell

textile mills, or teaching if they were better educated, it is no wonder the Observatory always had a long list of applicants. Pickering hired a few women because of special skills, but most got their jobs by connections or on the basis of their character. Searle wrote one applicant about the skills required: "A knowledge of ordinary arithmetic and a legible handwriting are all the necessary qualifications of a computer, although, of course, the more that is known of languages and mathematics the better."[40] Patience and cooperativeness were more important than any education beyond high school, and women even of the poorer classes had some opportunities to attend high school in this period. These low qualifications show that the Observatory did not hire these women to do original scientific work.

The women received a low but livable wage. The Observatory paid 25 cents an hour, and the women worked seven hours a day, six days a week, with one months paid vacation a year for full-time employees. R. S. Saunders, and probably a few other full-time employees as well, received a salary of $600 a year, which is very slightly more than 25 cents an hour. The majority of women, however, were paid by the hour. No regular schedule of raises for seniority existed, although Pickering gave raises to a few women who showed particular skill.[41] The base rate remained at 25 cents an hour at least through 1906.[42] Room and board could be found in 1875 for $6 a week, which

totals $312 a year.[43] Women could earn more teaching high school, reportedly $900 to $1,000,[44] but these jobs were hard to find in the cities (and often required a college education). Domestic and personal service, which employed 40 percent of women workers in 1900, and manufacturing, where another 25 percent worked, paid lower wages.[45] Members of the highest paid age bracket of female cotton mill workers in Massachusetts, 40-49 years of age, earned an average of 15.4 cents an hour according to a survey made in 1907-9.[46] The Observatory usually paid men the same rate for computing as women, but men considered this an unacceptable wage, and few applied for jobs. Male assistants who did the observing at night and other mechanical work received a higher salary, $800 a year in 1874.[47] A male salesman or principal clerk in a dry goods store or tea store usually earned $15 a week, $780 a year, in 1887.[48]

Between 1900 and 1920 the staff of women at Harvard remained large. Harvard could not compete in visual work with the larger telescopes being built in the midwest and particularly on mountains on the west coast, such as Yerkes and Mount Wilson. Therefore, in order to maintain its reputation, Harvard had to emphasize cataloguing and statistical studies of stars on photographic plates, because Harvard had the best plate collection in the world. Women accomplished much of the important astronomical work at

Fig. 8. Women at Harvard College Observatory in the late 1920s. Back row (left to right): Margaret Harwood, Cecilia Payne[-Gaposchkin], Arville Walker, Edith Gill; middle row: Lillian Hogdon, Annie Cannon, Evelyn Leland, Ida Woods, Mabel Gill, Florence Cushman; front row: Irene Crossman, Mary B. Howe, Harvia Wilson, Margaret Mayall, Antonia Maury (courtesy of Harvard College Observatory, identified by Margaret Mayall).

Harvard in this period, because women measured and studied the plates, as well as doing the necessary routine computation. In 1910, 21 women worked at the Observatory; by 1920 there were 16 (the reason for this decrease is unclear). The women hired were better educated than before. The previous experience of eight of the 20 women hired between 1900 and 1920 is known. Of these, four definitely graduated from college, one more probably did, two definitely did not have a college education, and the last one probably did not. Some of these women computed for the men researchers, but most worked in the photographic department.

The case of Harvard College Observatory shows how women first became involved in astronomical work at observatories. Harvard did not hire women to do original scientific work, but it did give them some opportunities. After studying at a woman's college, a woman who wanted to pursue a scientific career would not find work at a major observatory an ideal next step. It did, however, at least provide some possibility of a career. After 1900 more college graduates were hired, and photographic work provided more opportunities to use their scientific training. Although the astronomical institutions had not yet fully incorporated women as scientists, a woman could at least pursue some sort of a scientific career in astronomy, which had not been possible before in the United States.

CHAPTER IV

WOMEN'S CAREERS IN ASTRONOMY

A broader survey of the typical careers of women astronomers is necessary as a basis for the discussion of those who did notable scientific work. A statistical study of the 164 women astronomers who turned up in the course of this project is given in appendix A. This chapter describes the career patterns shown as prevalent by the statistical analysis. One example of a woman who did not succeed will be treated in some depth because it provides insight into the problems women faced and into what happened to the women who did not stay in astronomy. Because the most complete information is available on the graduates of the women's colleges, their careers will be considered in the most detail. One of the most unexpected discoveries of this research on women astronomers was the large number of observatories which hired women; hence some of these observatories will be described.

Career Patterns

Many of the women doing astronomical work did not have college educations. This was the case at Harvard, as has been shown above, and it was no doubt true also at

the other large observatories that hired women. These women were less likely to be mentioned in the astronomical journals, so it was difficult within the scope of this project to find out anything about them, except at Harvard where the archival material was accessible.

The first generation of teachers at the women's colleges also usually did not have college educations; there were very few places where they could have studied. Maria Mitchell at Vassar was mostly self-educated, as was Sarah Whiting at Wellesley. Elizabeth Bardwell had attended Mount Holyoke when it was a seminary rather than a college, and was hired to teach there immediately after finishing her studies. Mary Byrd at Smith was the exception; she had attended the preparatory department at Oberlin, one of the first coeducational colleges, and earned a B.A. from the University of Michigan. The only notable woman professor of astronomy at a coeducational college in this period, Susan J. Cunningham, professor of mathematics and astronomy at Swarthmore from 1874 to 1906, had studied for a year at Vassar but had not taken a degree. The 1860s and 1870s were a period in which science was still establishing itself in American universities, so degrees were not a requirement for men or women.

By 1890 the women's colleges were producing substantial numbers of graduates with training in astronomy, and they began to take over from the women without college educations

and make important scientific contributions. A few of these women stayed to succeed their teachers as professors of astronomy. The majority (63 percent of the sample) worked at least briefly at research observatories, and almost half (43 percent) taught high school at some time in their careers. Many eventually got married and stopped work or changed to a different field, but at least 14 women's college graduates before 1920 made a career in astronomy and worked at one observatory or college for more than ten years.

The first step for the women astronomers after graduating from college could be to take a job as a computer at an observatory, but many either studied for a masters degree or worked as an assistant at the college from which they had graduated. A good number of women earned masters degrees alone (37 percent), mostly from women's colleges, and a few earned Ph.D.'s as well (18 percent). Next, the women who continued their careers usually found permanent jobs at an observatory or college. A few women changed jobs frequently, but usually they changed eventually to something entirely outside of astronomy. Each teacher at a women's college chose one of her students as her successor and hired her as an assistant; after about 1910 many of the women's colleges also hired assistant professors of astronomy.[49] Some of the women at the women's colleges spent summers studying at some university or working at one of the big research observatories.

Women in Observatories

Yerkes was one of the observatories that employed the most graduates of women's colleges. Opened in 1897 with George Ellery Hale as the first director and connected with the University of Chicago (although situated away from Chicago in the town of William's Bay), Yerkes had a 40-inch telescope that is the largest refractor ever built. Yerkes offered volunteer summer fellowships to women, which particularly attracted professors at women's colleges who wanted to do research. Yerkes also hired women for permanent jobs computing and measuring plates. One of the programs women worked on was a study of parallax, under a grant from the Carnegie Foundation.[50] Emily E. Dobbin, who studied at the University of Chicago and worked at Yerkes, published papers in the Astronomical Journal and the Astrophysical Journal.[51] Of the 164 women whose careers are known (see appendix A), twelve worked at Yerkes, eight for less than two years, three for two to five years, and one for more than five years.

The next observatory founded by G. E. Hale, Mount Wilson, also hired large numbers of women. Mount Wilson is isolated on a high mountain in California, and women astronomers were not allowed to observe there at night until the 1960s,[52] ostensibly because there were no accomodations for them, but there were laboratories and offices in the town of Pasadena at the foot of the mountain. Mount Wilson hired

Fig. 9. "Some of the Observatory Staff and their Means of Conveyance," Members of the Staff of Mount Wilson in 1910 (Popular Astronomy 18 (1910): 494).

many Vassar graduates, but there was also a Smith graduate, Myrtle L. Richmond, who worked there from 1913 to at least 1935. Jennie Lasby, who had an M.A. from Mount Holyoke, worked at Mount Wilson and published papers in Popular Astronomy,[53] and Janet T. Howell, another Mount Wilson employee, published a paper in the Astrophysical Journal.[54] Twelve of the 164 women who were discovered in the course of this study worked at Mount Wilson, three for less than two years, two for two to five years, three for more than five years, and four for unknown lengths of time.

Women also made important contributions at the Naval Observatory. One of the earliest government scientific institutions, the Naval Observatory in Washington, D.C. was the subject of continual battles about how it was to be supported and what sort of research should be done there. Sometimes these difficulties prevented significant original work, but particularly under the leadership of Simon Newcomb it became one of the foremost American observatories. The Naval Observatory appears to have employed women particularly for investigations of comets and minor planets. Eleanor A. Lamson and Etta M. Eaton, the latter a graduate of Mount Holyoke, each calculated a number of orbits that were published in the Astronomical Journal.[55] An article on "What Women Have Done for Astronomy in the United States" mentions that Elizabeth Davis, who had studied at Johns Hopkins, "at one time held the position of professor of

mathematics at the Naval Observatory."[56] There is, however, no other evidence for this statement, and it seems unlikely that she held a professorship because the professors at the Naval Observatory had to be Naval officers. Six of the women studied worked at the Naval Observatory, two for less than two years, three for more than five years, and one for an unknown length of time.

Most of the other large observatories also employed women. In 1896 Columbia hired its first woman, F. E. Harpham, who had an M.A. from Carleton College and had worked for three years as an assistant at Smith.[57] Columbia employed a group of women computers who worked on such projects as a new reduction of Piazzi's star catalogue. Yale also employed women for cataloguing. The most notable woman at Yale, Margaretta Palmer, who earned a Ph.D. from Yale in 1894, worked on the Yale Index to Star Catalogues and also calculated a number of comet orbits.[58] Lick Observatory employed at least four women and Allegheny had at least two. The staff list of the Dudley Observatory shows 24 women on the observatory staff between 1904, when the first women were hired, and 1920.[59] Carleton College, a small coeducational school in Northfield, Minnesota, gave degrees to at least four women astronomers.[60] In addition, the Goodsell Observatory at Carleton College employed at least two women, one of whom, Charlotte R. Willards, a graduate of Smith, was a co-editor of Popular Astronomy for its first three years. Even the National Argentine Observatory in Cordoba, Argentina, hired two women from

the United States in 1913. One of them, A. Estelle Glancy, had earned a Ph.D. from the University of California in 1913 and had been employed for two years at Lick. She worked in Argentina for many years and made valuable observations of comet positions.[61]

Women in Scientific Societies

Women established a place for themselves in astronomy not only by their employment at most of the major observatories, but also by their participation in astronomical societies and conferences. No major professional astronomical society existed in the United States before 1898, when the Astronomical and Astrophysical Society of America was established. The Astronomical and Astrophysical Society accepted women members from the start; in fact, ten women were among the 51 participants in the 1898 conference at Harvard where the Society was founded. The women's own fears limited them more than any prejudice they met from the men; papers written by women were on the programs of virtually all the meetings of the Astronomical and Astrophysical Society, but they were often read by men. Caroline Furness wrote of the dedication of the Yerkes Observatory in 1897:

> The social informality of the occasion was delightful, and if we seemed more serious and less unbending than our confrères, it was because we were not yet sure of the place which women held in the astronomical world and did not dare to be unscientific or frivolous even for a moment.[62]

Most American scientific societies were broadminded about

Fig. 10. The 0th (organizational) Meeting of the Astronomical and Astrophysical Society of America in 1898 at Harvard (courtesy of Owen Gingerich).

the admission of women. The American Association for the Advancement of Science admitted women members from the start, following the precedent set by the American Academy of Arts and Sciences, which had accepted Maria Mitchell as a member.[63] In Germany, women astronomers were not so welcome. The Astronomische Gesellschaft decided in 1897 not to admit Mary Whitney because the admission of ladies was "incompatible with the bylaws of the Society."[64]

An Unsuccessful Woman

Not all women were successful in pursuing astronomical careers. Many women started out with promise but did not end up in astronomical work. Patterns are hard to establish, except that many women left to get married. The example of one unsuccessful woman, whose story happens to be well documented, reveals some of the limitations of the opportunities open to women in this period.

Mary Wagner had studied at Vassar for two years when she wrote to Pickering at Harvard College Observatory in 1893 asking for a job (this correspondence is given more fully in appendix B). She wrote:

> Before entering college, I taught five years and received a fair salary. I have no doubt that I can get nine or ten hundred dollars a year in some high school, but I would much prefer a six or seven hundred dollar position in an observatory, and if there is an opportunity to study or to advance myself in any way, I might be willing to take less.[65]

Pickering wrote back that there was a position, but it might not be suitable because the work required was partly clerical and partly routine computing, at a salary of $500 a year.[66] Wagner replied that she was willing to compute or do whatever else was required of her, but "I am more fond of practical work and have a good eye for seeing; I have used the telescope, microscope, and spectroscope a great deal."[67] Arthur Searle wrote back to her (because she was to be employed in his department): "I fear that there will be little opportunity for you here in the way of telescopic work,"[68] and suggested that she visit the Observatory to find out more about the job. After some deliberation, Wagner accepted the job, writing: "It hurts my pride to work for five hundred dollars, but I have a great desire to see your observatory and to work there for a year must surely be instructive to me."[69]

Mary Wagner worked at Harvard from September to the first week of December of 1893. The correspondence resumes in December, when she suddenly returned to her home in Minneapolis to take care of her seriously ill mother. From her home she wrote Searle to ask about her pay. She thanked him for his kindness and wrote: "It seems to me that I ought to beg your pardon for complaining to you so often about the work. I hope your new assistant, if you have one, may find joy in cataloguing stars and that she may have no other ambition than to do that well."[70] In her next letter

she asked whether it would be possible for her to return to work, because, while she did not like the work, she preferred not to leave the impression that she had been fired. She felt that she could be content if her duties were different:

> If I can use the telescope evenings and work four hours a day on the catalogues, I will be satisfied. I should like to have some opportunity of showing you and Prof. Pickering that I can do some good work. If the burden of poverty is not so heavy I shall be happier.[71]

She was not invited back, but Pickering sent her a letter of recommendation at her request.

Wagner wrote a final letter to the Observatory in February saying that she had been unsuccessful in finding a job teaching high school, but was giving private lessons and planning on studying zoology at the University of Minnesota. She wrote:

> It breaks my heart though when I think of the wooden post that I watched with so much interest from my prison window. I should like to know whether the telescope has been mounted or not. If I had not been so very poor, I would have been delighted with the prospect for I like to observe and I have a good eye, but Astronomy must be left in the hands of the wealthy, while I turn to something that will give me a living.[72]

Vassar alumnae records show that Wagner received a B.A. from the University of Minnesota in 1897 and taught mathematics and science in high schools. In 1902 she opened an inn in Poughkeepsie, New York, which she owned and managed for 20 years. In a letter to Mary Whitney, Pickering gave his final view of the incident:

> Miss Wagner's work was very satisfactory to Professor Searle, to whose department it was mainly confined, but she found the monotony of ordinary computing too much for her, although care had been taken before she came to explain to her that there was no prospect of pecuniary returns for work of a more interesting character.[73]

Wagner's letters show that she was not a stable person, but her complaints tell what others may have felt but not said.

Mary Wagner's letters show that a woman with good scientific training from a women's college might have trouble finding what she considered a suitably challenging job. Without archival research at other large observatories it is impossible to say whether there were more challenging opportunities open to women there than at Harvard. Certainly there were similar opportunities open, although it is probably significant that women at other observatories did not make as important contributions to science as did the women at Harvard.

CHAPTER V

SCIENTIFIC WORK AT THE WOMEN'S COLLEGES

While the professors at the women's colleges did not do scientific work of the same importance as that done by women at Harvard, they did try to carry on research in addition to their teaching. The next chapter will show how the women at the observatories, even the women who made important contributions to science, were limited by their place as employees in a large institution. At the women's colleges the professors could select their own research topic and were free to develop their results on their own. The fact that even with these freedoms they did little scientific work of significance reflects not necessarily on their talent but on the limitations placed on them by the job they were hired to do and on the social constraints that acted on them. Rather than treating just one example, most of the women's colleges will be discussed so as to fill out the picture of the place of women in astronomy in the late nineteenth and early twentieth centuries.

Women wrote four percent of the papers in the three major astronomical journals in the United States between 1890 and 1920.[74] The number of papers by women varied from

Fig. 11. Women at the 1920 meeting of the American Astronomical Society at Smith College. Left to right: Margaretta Palmer (Yale), Sarah Whiting (Wellesley), Harriet Bigelow (Smith), Mary Hopkins (Smith), Anne Young (Mt. Holyoke), Helen Swartz (South Norwalk, Conn.), Annie Cannon (Harvard), Antonia Maury (Harvard), Caroline Furness (Vassar), Leah Allen (Wellesley), D. Peck (Smith ?), Vera Gushee (Smith). (Sky and Telescope 28 (1974): 293.)

a low of 19, or 1.3 percent, in the Astrophysical Journal, through 103, or 3.9 percent, in the Astronomical Journal, to a high of 116, or 6.1 percent, in Popular Astronomy. Figure 12 gives five year averages of the percentage of papers by women, but shows no trends strong enough to show through the statistical flunctuations. Appendex A gives more detailed results. Minor notes in the Astrophysical Journal and regular departments in Popular Astronomy are not included in these figures. Of these 238 papers by women, 48 percent were written by women at the women's colleges. This does not indicate that the amount of scientific work done at the women's colleges was as great as the amount done by women at observatories, because much of the work done at observatories was recorded in the publications of those observatories rather than in journals.

The history of the astronomy department at Vassar has already been discussed, and the strong leadership described there resulted in the largest amount of scientific work of any of the women's colleges. A bibliography of the publications of the staff of the Vassar College Observatory while Whitney was director lists 102 articles and other publications.[75] Thirty of the notes and papers listed are observations of comets, 27 are observations of minor planets, and 22 concern variable stars. These subjects were taken up approximately consecutively: the most important work at Vassar was comet observations until the mid-1890s, then minor planets

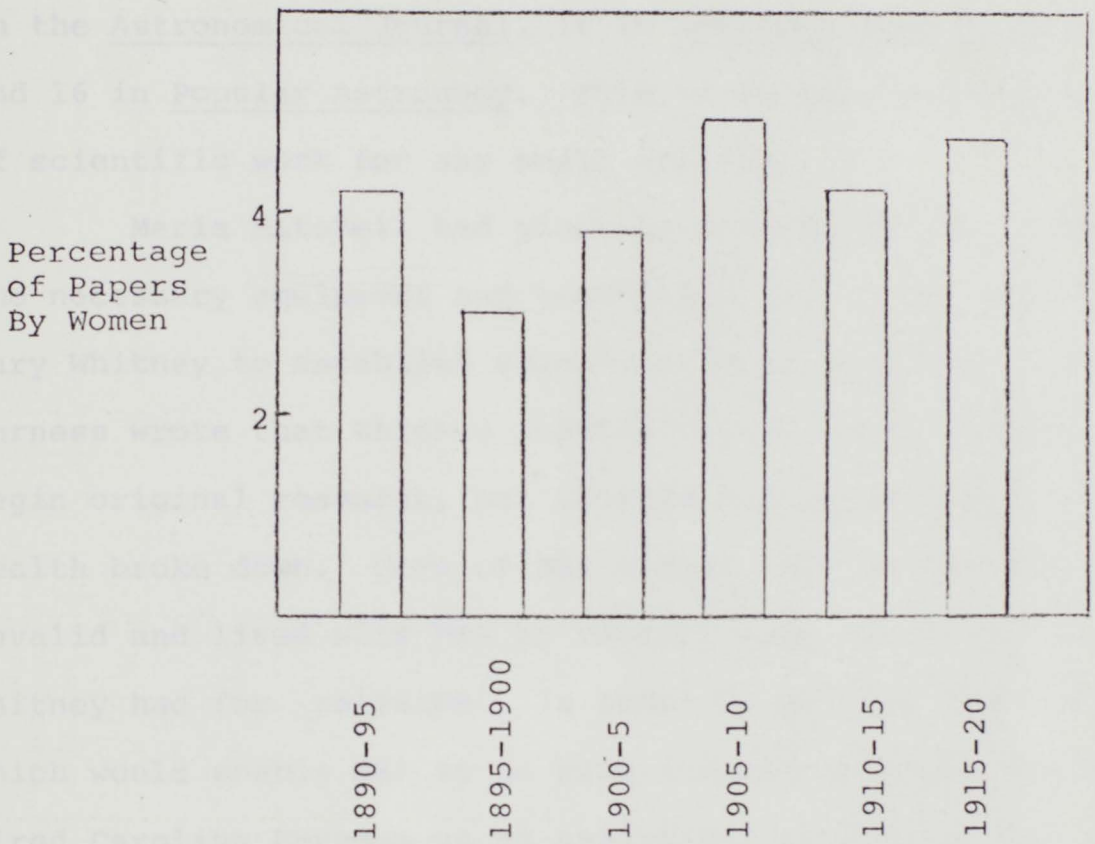

Fig. 12. Five Year Averages of the Percentage of Papers by Women in the Astronomical Journal, the Astrophysical Journal, and Popular Astronomy.

were emphasized, then in 1901 observations of variable stars were started. Fifty-nine of these papers were published in the Astronomical Journal, 18 in Astronomische Nachrichten, and 16 in Popular Astronomy. This is an impressive body of scientific work for any small college.

Maria Mitchell had given her energy to obtaining the necessary equipment and teaching,[76] so it was left to Mary Whitney to establish scientific work at Vassar. Caroline Furness wrote that Whitney started out at Vassar eager to begin original research, but shortly thereafter her sister's health broke down. Care of her sister, who became a permanent invalid and lived with her at Vassar, took up what free time Whitney had for research. In order to get the assistance which would enable her to do some scientific work, Whitney hired Caroline Furness as an assistant, paying for her out of her own pocket. Within a few years Whitney's mother and sister both died, and by 1894 Whitney was free to devote herself to science and start an ambitious research program.[77] Whitney was an excellent mathematician, and this resulted in an interest in orbits and observations of minor planets. Benjamin A. Gould, editor of the Astronomical Journal, encouraged this work by publishing the results and writing: "I wish to congratulate you on the useful service your observatory is doing in these observations of asteroids which you are so persistently following."[78] Vassar could make a greater contribution by observing regularly a minor planet or variable

Fig. 13. Mary W. Whitney (Popular Astronomy 30 (1922): facing p. 600).

star that was not regularly followed elsewhere than by observing comets, which attracted the attention of astronomers all over the world. Brian Marsden, who has recently calculated the orbits of some comets in the 1890s, says that the observations from Vassar were not in large enough quantity to be particularly useful.[79]

The teaching of astronomy at Mount Holyoke actually began even earlier than at Vassar, but no original scientific work was done there until about 1900. Mount Holyoke was founded in 1837 as a female seminary, and did not officially become a college offering an education comparable to a men's college until 1888. The teacher of astronomy, first at the seminary and later at the college, was Elizabeth M. Bardwell. Mount Holyoke had been given a six-inch telescope in 1853, and in 1881 a trustee gave money for an eight-inch equatorial (the last one made by the elder Alvin Clark), a three-inch meridian circle, and a building to house them, called the John Payne Williston Observatory. Bardwell studied at Dartmouth in 1873-4 and Charles A. Young, a notable astronomer whom she had known at Dartmouth and who later worked at Princeton, visited Mount Holyoke every year from 1869 to 1908[80] to give a short course of lectures, so the students probably got a reasonably good education. Young wrote of Bardwell:

> While perhaps she was not particularly rapid in her mental processes she was very sound and clear in her understanding and had an excellent ability to communicate her knowledge to others. She was therefore an admirable teacher, inspiring, diligent, conscientious, and 'faithful unto death.'"[81]

After the death of Elizabeth Bardwell in 1899, Anne Sewell Young became professor of astronomy. The niece of Charles Young, Anne Young had graduated from Carleton College in 1892, taught school for three years, and received an M.S. from Carleton in 1897. Well trained in research, she had in fact published in astronomical journals before she was hired by Mount Holyoke.[82] In 1900, Young started a program of daily sunspot observations at Mount Holyoke, and after 1907 these observations were sent regularly to Zurich as part of a world-wide cooperative project. Other scientific research at Mount Holyoke included asteroid positions, comet orbits, and extensive work on variable stars. This was all that Young could do with the equipment available at first, except during some summer which she spent at Yerkes, and work she undertook at Columbia for which she received a Ph.D. in 1906. In 1912 a Gaertner measuring engine was purchased for making measurements on photographic plates, which were borrowed from Yerkes.[83] Young was able to hire an assistant to help with the teaching and research starting in 1902.

Similar work was pursued at Smith College. The Smith College Observatory was founded in 1887, and Mary Emma Byrd became the first director.[84] A graduate of the University of Michigan, Byrd had been the principal of a high school in Indiana, had studied for a year under Pickering at Harvard, and had worked for five years as an

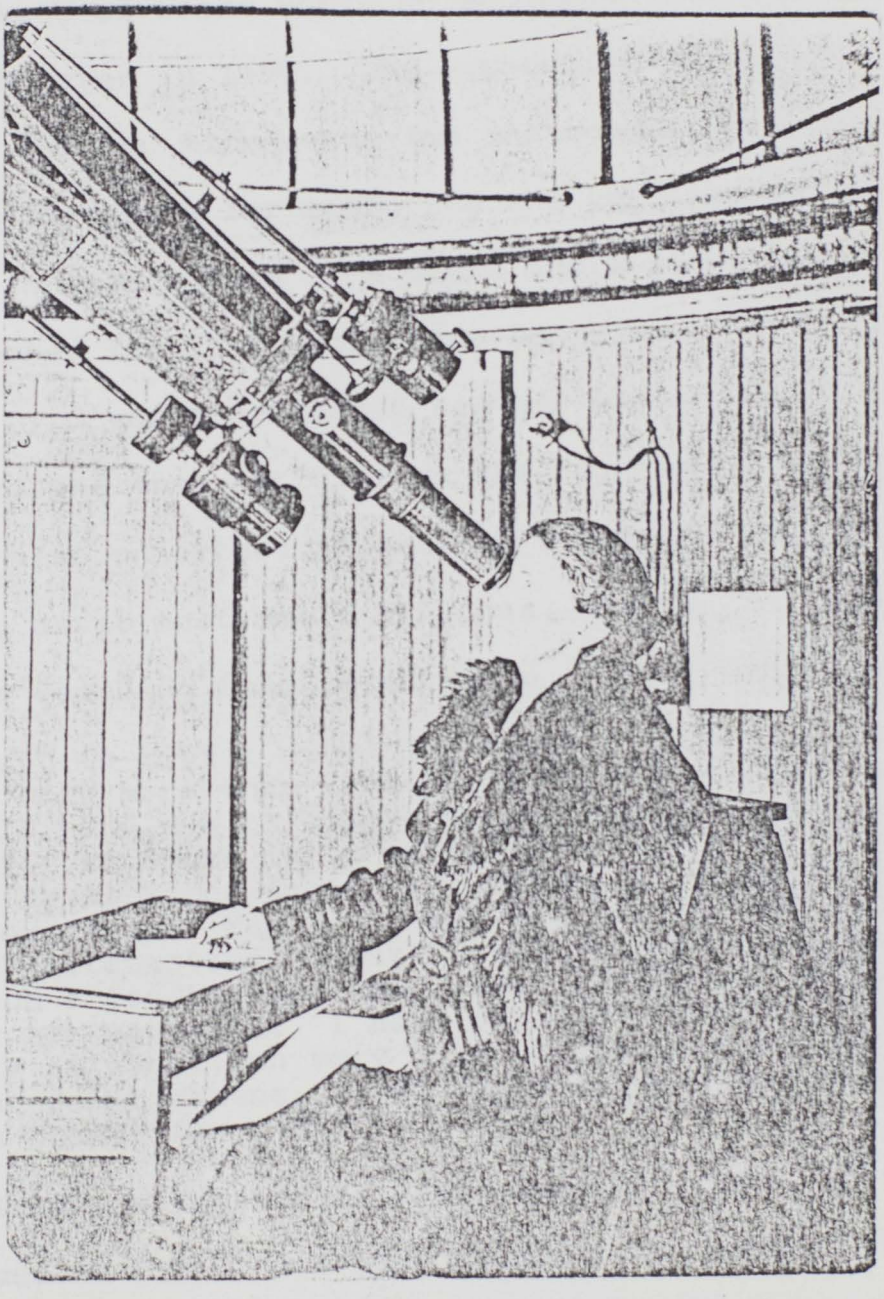

Fig. 14. Anne S. Young (Mount Holyoke College Archives).

assistant at the Goodsell Observatory of Carleton College. The Smith Observatory had an 11-inch equatorial and a small meridian circle, but no regular income for maintenance and purchase of books until an endowment was give by Elizabeth Haven in 1898. The equatorial lacked electric lighting for the micrometer (an instrument attached to the telescope eyepiece for measuring the angular distance between an object such as a comet and a star) until students raised money for it by voluntary contributions in 1891-92.[85]

Byrd was a dedicated teacher who published two textbooks and many articles on the teaching of astronomy, but she also undertook scientific research. The worst problem, as at most small colleges, whether for women or men, was teaching load; Byrd wrote in an annual report in 1892-93:

> Except in bitter midwinter weather this year, there have not been more than three or four nights a term when I could handle a telescope for any purpose save to adjust it for students until after ten o'clock at night; and my work begins in the morning at eight or half after eight. May I beg you to consider how short, under such circumstances, must inevitably be the time during which a teacher can keep fresh springs of inspiration for her students. I have put off the evil day by working late at night, on very cold nights, and by spending since last Commencement, seven weeks of vacation time at the observatory.[86]

An assistant was hired in 1893, but the number of students continued to grow. The main subject of research was comet positions, four sets of which were published in the Astronomical Journal from 1894 to 1904. When the Astronomical Journal did not publish observations that she sent them in 1905, Byrd wrote Pickering for help: "The truth is that we work so

hard here to carry on a little independent work, living, I might almost say, for the sake of comets that come within the reach of our glass until observations and reductions are completed, that this attitude on the part of the Journal is no small disappointment."[87] With the help of a letter of introduction from Pickering these observations were published in the Astronomische Nachrichten.[88]

Byrd retired in 1905 and was succeeded by Harriet Williams Bigelow. Byrd's retirement came at the early age of 57 as a protest against the acceptance by Smith of what she considered to be tainted money, gifts from Rockefeller and Carnegie.[89] Bigelow had worked at Smith as an assistant since 1898 and had earned a Ph.D. from the University of Michigan in 1904. She kept a research tradition going at Smith and published seven papers, mostly on comets, in the Astronomical Journal.[90] Smith produced five women who pursued astronomical careers at women's colleges, but only two who are known to have worked for more than five years at a large observatory.

Two more eastern women's colleges, Radcliffe and Wellesley, offered instruction in astronomy and produced some important women astronomers, but little scientific research was done there. At Radcliffe, astronomy was taught by Arthur Searle and John Edmands of Harvard College Observatory,[91] and some students who showed scientific talent were hired by the Observatory. At Wellesley Sarah F. Whiting

Fig. 15. Sarah F. Whiting (Popular Astronomy 35 (1927): facing p. 539).

developed one of the first undergraduate teaching laboratories in physics in the country, with the help of E. C. Pickering. She wrote of her experiences: "For many years I was almost alone in college work in this line meeting the somewhat nerve wearing experience of constantly being in places where a woman was not expected to be, and doing what women had not at that time conventionally done."[92] Whiting taught a course in astronomy, but Wellesley did not have an observatory until 1900, by which time Whiting was more dedicated to her teaching than to astronomical research.

The professors at Vassar, Mount Holyoke, and Smith all pursued some scientific research. That this research did not produce scientific work of enough value to bring them fame is due to other demands on their time and energy and to the sort of problems they chose to work on. Observations of variable stars are valuable, but like comet and asteroid positions and spectral classification, large amounts of work can be put into determining light curves that contributes only a small amount of data toward advancement in astronomical theories. Cecilia Payne-Gaposchkin said that in the first quarter of the twentieth century variable stars were considered a second-class problem.[93] The women at the women's colleges contributed small pieces to large research projects rather than pursuing new ideas. In a pamphlet encouraging amateurs and particularly women to observe variable stars, Pickering wrote:

> The criticism is often made by opponents of the higher education of women that, while they are capable of following others as far as men can, they originate almost nothing, so that human knowledge is not advanced by their work. This reproach could be well answered could we point to a long series of observations as are detailed below, made by women observers.[94]

Pickering wishes to show that women can contribute to human knowledge, but the work he advises them to do is not very original. This is a product of his implicit philosophy of science rather than of malice; the point is that women, even at women's colleges, were limited by this attitude.

CHAPTER VI

THE SCIENTIFIC WORK OF THE WOMEN AT HARVARD

The most notable achievements of women astronomers in the United States in this period were made by four women at Harvard College Observatory: Williamina Fleming, Antonia Maury, Annie Cannon, and Henrietta Leavitt. The opportunities available to women at Harvard to do original work may have been larger than at other observatories, but much of the reason for the preëminence of Harvard women can be found in the approach to astronomy followed at Harvard. Pickering stated his philosophy in his introduction to the Henry Draper Catalogue prepared by Annie Cannon. He wrote:

> In the development of any department of Astronomy, the first step is to accumulate the facts on which its progress will depend. This has been the special field of the Harvard Observatory. An attempt is made to plan each investigation on a scale that it will not be necessary to repeat it shortly, for a larger number of stars. Speculations unsupported by fact have little value, and it is seldom necessary in such investigations as are carried on here, to form a theory in order to learn what facts are needed. An observer also is likely to be prejudiced if he has already formed a theory to which he thinks the facts should conform.[95]

Pickering found women ideal employees for such large scale work requiring little theoretical understanding. He was right in considering such investigations important, and the women who did them were praised by grateful astronomers.

However, this approach did not allow the women to pursue independent theoretical work, as some had the ability to do.

Williamina Fleming

Williamina Paton Stevens Fleming was the first of the Harvard women to become famous, and her background and education are different from the other notable women. Fleming was born in 1857 in Dundee, Scotland, the daughter of a prosperous craftsman. She attended the public schools there and worked as a student teacher. With her husband, James Orr Fleming, whom she had married the previous year, she immigrated to Boston in 1878. A year after coming to the United States her husband deserted her, and she found a job as a maid or housekeeper in the house of Edward C. Pickering, director of Harvard College Observatory. In 1879 she had a son, Edward Pickering Fleming.[96]

A legend has grown up about how Fleming came to work at the Observatory. As Dorrit Hoffleit (who did not know her) tells the story, Pickering adopted the system of objective prism photography of spectra, and many beautiful plates were being taken. He wanted to use the material to set up a spectral classification system, so he assigned some male assistants to study the plates, but the work did not progress satisfactorily. One day Pickering became so annoyed with the lack of progress that he went out of the building in a huff, vowing that his Scotch maid could do a better job. And so he hired her.[97] Other evidence casts

Fig. 16. Williamina Fleming (courtesy of Harvard College Observatory).

doubt on parts of this story. All Pickering himself wrote about Fleming's hiring in his official memorial was: "Mrs. Fleming began work at the Harvard Observatory in 1881. Her duties were at first of the simplest character, copying and ordinary computing."[98] When the Draper Memorial, which first made possible substantial work on spectra at Harvard, was founded in 1886, the first assistant to study spectra was Nettie A. Farrar. After a few months she left to get married, and Pickering wrote to Anna Draper that Farrar was "instructing Mrs. Fleming who has assisted me, and who will I think take her place satisfactorily."[99]

Fleming's most important scientific work was on the Draper Memorial. Pickering assigned her to study the spectra on the plates and develop an empirical classification system, which she would use to classify stars for a catalogue. Stellar spectra had previously been catalogued by a system proposed by Father Secchi of Rome on the basis of visual observations of spectra, which divided them into four classes, depending on which sets of spectral lines were brightest. Fleming, however, found that she could distinguish more varieties, and developed a system of 22 classes. The logic (though not the individual classes) of her system is described in Pickering's explanation of the ordering of the spectra in the introduction to the first Draper Catalogue. The types he refers to are those proposed by Secchi. Pickering writes:

> These lines may be divided into two classes,--first, those which predominate in many stars in the Milky Way, especially in the constellation of Orion, and second, those present in the solar spectrum. Nearly all the bright stars may be arranged in a sequence, beginning with those in Orion, in which the auxiliary lines are nearly as intense as those due to hydrogen. Other stars may be found, in which these lines become fainter and fainter, until they have nearly disappeared. The more marked solar lines then appear, become stronger and stronger, and the hydrogen lines fainter, until they gradually merge into a spectrum identical with that of the sun.... Continuing the sequence, the spectra pass gradually into those of the third type. Certain bands become more marked, and the spectra of the third type may be divided into four classes. In the fourth of these classes the hydrogen lines are bright instead of dark.[100]

In the Draper Catalogue, volume 27 of the Harvard Annals, Fleming classified 10,498 stars according to her system. The classifications are dependable, each class has its identifying features, but the order and division of the classes is limited by the fact that Fleming worked from plates with low dispersion spectra, usually less than an inch long, and the plates were occasionally of poor quality. A number of Fleming's classes later turned out to be defects in the image of the spectrum on the plate, and these extra classes made it difficult for her to arrange the spectra in a consistent order.

In her examination of the plates first in the cataloguing work and then as Curator of Astronomical Photographs, Fleming found many unusual and interesting objects. She discovered ten novae, more than 300 variable stars, and 59 gaseous nebulae.[101] Pickering published numerous notices in the Astronomical Journal about stars with unusual spectra that Fleming had discovered. He took responsibility for the

work, but always gave her credit for doing the actual studies. In a report on the 1898 conference at Harvard which resulted in the founding of the Astronomical and Astrophysical Society, her paper is described:

> The contribution of Mrs. M. Fleming, read by Mr. Pickering, Director, on "Stars of the Fifth Type in the Magellanic Clouds" contained some important statements in reference to the stars having spectra consisting mainly of bright lines, designated as Fifth Type.... In conclusion Professor Pickering said that Mrs. Fleming had omitted to mention that of these seventy-nine stars nearly all had been discovered by herself, whereupon Mrs. Fleming was compelled by a spontaneous burst of applause to come forward and supplement the paper by responding to the questions elicited by it.[102]

She published two papers in the prestigious Astrophysical Journal in 1895 under her own name, but most of her results were published by Pickering in Harvard Circulars and the Harvard Annals.

In later years her duties became more administrative, but she was honored by many astronomical societies for her earlier work. She held the position of Curator of Astronomical Photographs from 1899 to 1911, the first woman ever to receive a Corporation appointment from Harvard. She supervised and checked the work of the women assistants, with whom she was not popular,[103] examined the plates as they came in, corrected proofs for the Harvard Annals, and acted as Pickering's secretary. She was made an honorary member (because women were not allowed to be regular members) of the Royal Astronomical Society in 1906, only the fifth women member. She also belonged to the Astronomical and Astrophysical Society of America and the Société Astronomique de France.[104]

Antonia Maury

Pickering assigned the next major project of the Henry Draper Memorial to Henry Draper's niece, Antonia Caetana de Paiva Pereira Maury. Daughter of a minister and naturalist, Mytton Maury, Antonia received a B.A. from Vassar in 1887. She started work at Harvard in 1888 and continued to do at least occasional research at Harvard until 1935, mostly as a volunteer.

Maury investigated the spectra of bright northern stars as part of the Draper Memorial from 1888 to 1896. Pickering wanted to improve Fleming's classification system by a study of very detailed spectra made with two or three prisms in front of the telescope so that the light of one bright star forms a large spectrum on the plate, and he assigned this work to Maury. On these spectra the relative intensity of hundreds of lines could be studied to better understand the relationship between one spectral type and another. Being of independent character, Maury abandoned Fleming's classification almost entirely and developed her own system, which she felt divided the spectra into types with the most physical meaning. She described the intent of her classification system in the volume of the Annals that contained her results:

> As usual, the stars were arranged in an apparently progressive series, which in the present case was made to include twenty-two groups... But it also appeared that a single series was inadequate to represent the peculiarities which presented themselves in certain cases, and that it would be more satisfactory to assume the existence of collateral series.[105]

Fig. 17. Antonia Maury (courtesy of Harvard College Observatory).

This two-dimensional classification system anticipated Hertzsprung's discovery that stars of a given temperature, and therefore of the same spectral type by Fleming's and Cannon's systems, differed in size and luminosity. The second dimension of Maury's classification system is based on the width and sharpness of the spectral lines, and this characteristic is determined by the size and luminosity of the star.

The importance of this work was not recognized at Harvard. Maury's classification system was awkward because it used roman numerals for the main series. The determination of the second classification, the width and sharpness of the lines, required the study of more than one plate for each star because an apparent fuzziness could be due to poor focusing or sky conditions. Pickering would not commit extra resources and effort to cataloguing a distinction whose importance he did not see.

More importantly, Maury's system was not adopted because she did not stay at Harvard to apply it. She left the observatory in 1892 without completing her study because she was unable to work with Pickering. She taught school for two years, while Pickering anxiously tried to arrange for her to complete her work or agree to turn it over to someone else. Maury wrote to Pickering in 1892 about closing up her work:

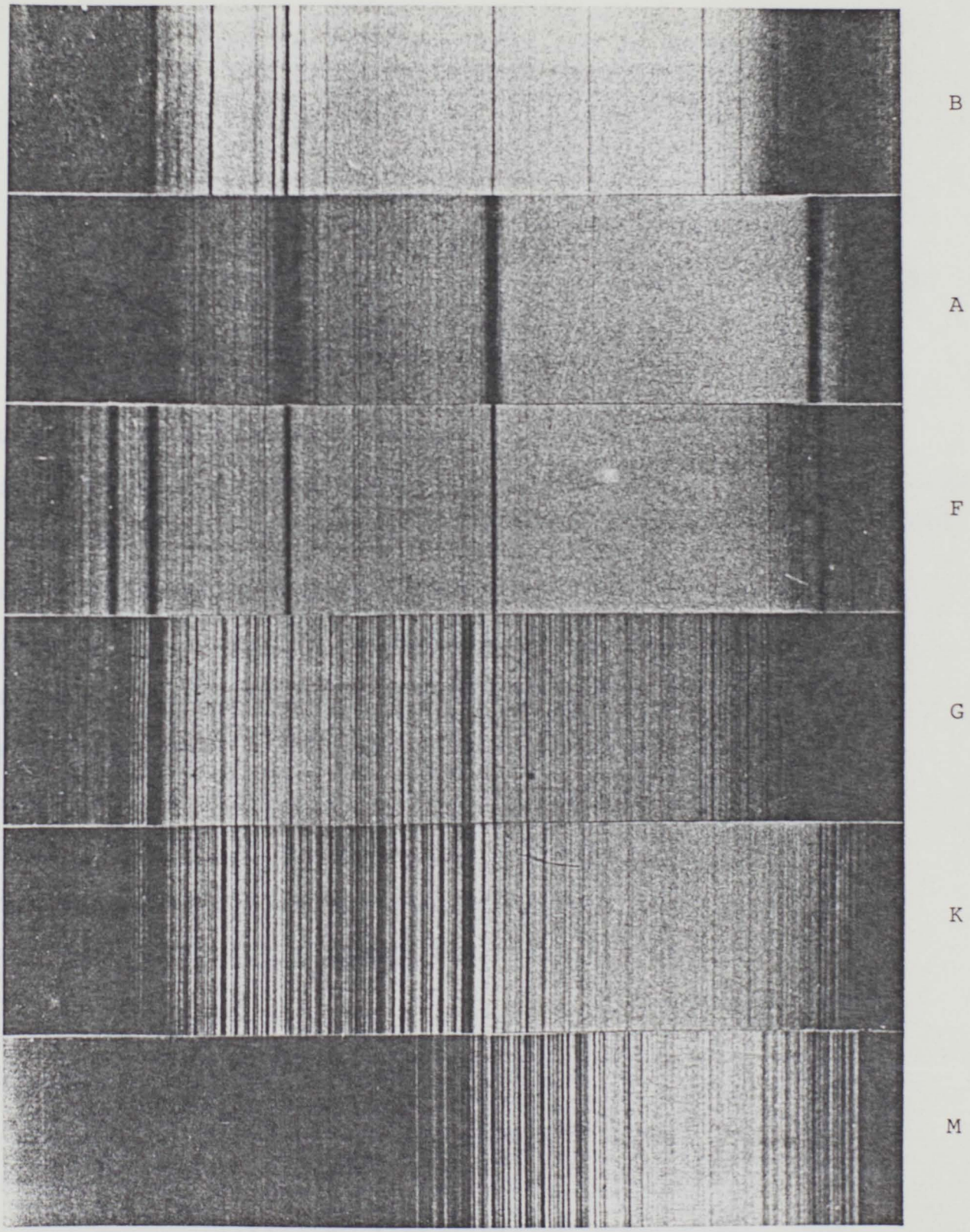

Fig. 18. Typical Large-Dispersion Spectra, as presented by Cannon, show the complexity of the problem of classifying spectral types in any detail (Harvard Annals, vol. 28, part 2, plates).

> I am both willing and anxious to leave it in a satisfactory condition, both for my own credit and in honor of my uncle. I do not think it is fair to myself that I should pass the work into other hands until it can stand as work done by me. I do not mean that I need necessarily complete all the details of the classification, but that I should make a full statement of all the important results of the investigation. I worked out the theory at the cost of much thought and elaborate comparison and I think that I should have full credit for my theory of the relations of the star spectra and also for my theories in regard to Beta Lyrae. Would it not be fair that I should, at whatever time the results are published receive credit for whatever I leave in writing in regard to these matters.[106]

Pickering wrote back that "It is the regular practice of this Observatory to make full acknowledgement in its publications of the credit due to authors of particular portions of them."[107] Despite this assurance, Maury's work was the first volume of the Annals to have a woman's name on the title page, for Fleming had received only an acknowledgement for the first Draper Catalogue. Pickering finally had Maury sign an agreement to finish or turn over the work by the beginning of 1893,[108] but she was still not finished in December of 1894, and still unable to work comfortably under Pickering. After one incident her father wrote the following letter:

> Dec. 19, 1894
>
> My dear Prof. Pickering:
>
> I was greatly concerned last night, when my daughter came home, to find from her that you had spoken to her in a tone and manner which greatly hurt her feelings. I cannot believe that you were conscious of it, for I am quite sure that you would not willingly have spoken as you did. Of course my daughter is inexperienced in preparing matter for the press, and is far from unwilling to listen to any suggestions. She is glad to receive them. But you may judge of the impression which you have produced, when I tell you that I am convinced, were it not for other considerations, she would never enter the Observatory again as your assistant, and

> seeing how she feels I should not be willing that she should. I scarcely need say to you that though she is working in the Observatory, she is a lady and has the feelings and rights of one. I am sure you cannot wish to injure either.
>
> Yours truly,
> Mytton Maury[109]

Despite these problems the study was finally put together and published in volume 28 of the Harvard Annals in 1897.

Though part of the problem was a personality conflict, Pickering did not appreciate the detailed, theoretical classification system Maury wished to develop. In an undated letter, probably written after her study of spectra had been finished, Maury wrote:

> But although I several times before have taken offence at things you have said to me I have always decided in the end that the only trouble was that I, being naturally unsystematic was not able to understand what you wanted and that you also, not having examined minutely into all the details, did not see that the natural relations I was in search of could not easily be arrived at by any cast iron system.[110]

Her search for a natural classification system conflicted with Pickering's philosophy, quoted in the introduction to this chapter, that "it is seldom necessary in such investigations as are carried on here, to form a theory in order to learn what facts are needed." Dorrit Hoffleit, who knew Maury in the 1930s, said that Pickering "did not think as highly of her as she merited" and that "I am convinced that Miss Maury was an original thinker."[111] Cecilia Payne-Gaposchkin, who came to Harvard in 1923, described her:

> Miss Maury was sensitive, imaginative, affectionate, and I feel as if she was a rejected sort of person. I don't know if anyone had ever shown her much affection.

> She was very homely; that was one of her drawbacks, I suppose. She was always inquiring, always thinking, always trying to arrange things in her mind in a logical sequence and see what caused them.... Perhaps she was easily hurt, but she was not aggressive in any way. She was very much the reverse of aggressive except when she was roused by injustice, to other people mostly.... She was a woman of great courage and warmth of heart.... Of course, I only knew her when she was old. I was very fond of her, but she just talked and talked and talked and talked. You couldn't do any work because she wanted to talk so much. It was just she needed an outlet; she needed to discuss. Nobody had ever listened to her, nobody had ever responded to her scientific questionings, I think.[112]

Hertzsprung recognized the importance of Maury's two-dimensional classification system. He wrote to Pickering in 1908 to protest the omission of Maury's second dimension, which she had indicated with the letters a to c, from a later catalogue (in his own uncertain English):

> But in one respect I have been disappointed and I allow me directly to say a few words on that point.
>
> On my opinion the separation by Antonia C. Maury of the c- and ac- stars is the most important advancement in stellar classification since the trials by Vogel and Secchi. But in the new catalogue the spectra of some of them as Alpha Cygni and Delta Cephei are not even mentioned as peculiar.
>
> It is hardly exagerated to say that the spectral classification now adopted is of similar value as a botany which divide the flowers according to their size and color. To neglect the c- properties in classifying stellar spectra, I think, is nearly the same thing as if the zoologist, who had detected the deciding differences between a whale and a fish, would continue in classifying them together.[113]

Maury's work helped Hertzsprung on the road towards his contribution to the discovery of the Hertzsprung-Russell diagram.

Maury's other major scientific investigation was a study of the spectroscopic binary Beta Lyrae. In 1889 Pickering had discovered the first spectroscopic binary,

a double star whose two components cannot be separated visually but which shows itself to be double by a periodic doubling of the spectral lines (when the stars are in such a position in their orbits that their spectra are doppler shifted in different directions). Maury discovered the second such star, Beta Aurigae, shortly thereafter. She studied the particularly complex spectroscopic binary Beta Lyrae for many years. She did not work steadily at Harvard on this research; she spent time studying spectra visually at Vassar (in 1896), teaching high school, giving lectures, and pursuing her interest in ornithology, but she investigated this star in great depth. Beta Lyrae is a close double star (so close that the two stars are nearly in contact), but the spectrum of the system shows variations of longer term than the period of the stars, and an irregular variation which Maury could not explain.[114] Helen Hogg, who did graduate work at Harvard in the early 1930s and knew Maury then, said that perhaps Maury got stuck on too big a problem when she tackled Beta Lyrae.[115] She made major contributions to the understanding of this star and visited Harvard annually to check on its behaviour until 1948.[116] But as Cecilia Payne-Gaposchkin said: "She had a flair for picking out tremendous problems. If you look at the literature for Beta Lyrae you will see that nobody has ever solved the problem."[117] Maury died in 1952 at the age of 86.

Annie Cannon

The spectroscopic work that Maury abandoned was continued by Annie Jump Cannon, who had already started work on the southern stars before Maury finished the northern. Daughter of a prosperous shipbuilder and state senator, she was born in 1863 and graduated from Wellesley in 1884. Partially deaf from an early age, she spent the next ten years at home in Dover, Delaware as a dutiful daughter, though she wrote in her journal:

> I am sometimes very dissatisfied with my life here. I do want to accomplish something so badly. There are so many things that I could do if only I had the money. And when I think that I might be teaching and making the money, and still all the time improving myself, it makes me feel unhappy and as if I were not doing all I can.[118]

In 1894, after the death of her mother, she returned to Wellesley as an assistant in the physics department, and in 1895 she studied astronomy as a special student at Radcliffe.[119] In 1896 she started work at Harvard College Observatory, where she remained until 1941.

In the same volume of the Annals as Maury's classification of the spectra of bright northern stars is Cannon's investigation of bright southern stars, published in 1902. In this third major Draper study the stars are classified by a third spectral classification system, developed by Cannon from her detailed study of spectra photographed at the Harvard station in Arequipa, Peru. Pickering explained that: "In all three cases, it was deemed best that the observer should place together all stars having similar spectra and thus form

Fig. 19. Annie Cannon at Oxford (courtesy of Harvard College Observatory).

an arbitrary classification rather than be hampered by any preconceived theoretical ideas, or by the previous study of visual spectra by other astronomers."[120] He explained that the different classification systems could be freely translated. Cannon rearranged Fleming's classes to the sequence which Maury had discovered, eliminated the spurious classes, added numbers for finer gradations, and dropped Maury's second dimension refering to the sharpness of the lines except when the star was unusual enough to be marked peculiar. The sequence of classes, which Fleming had labelled alphabetically, became O, B, A, F, G, K, M and in this first catalogue the decimal divisions are indicated between two letters, so that a star half way in type between class B and class A is labeled B5A.

Having developed a satisfactory classification system, Cannon next set about applying it on a large scale. The first volume of her Henry Draper Catalogue was published in 1918 as volume 91 of the Harvard Annals. The entire catalogue contains 225,300 stars, and when it was finished she started work on an extension. The stars are catalogued according to the system she developed for the bright southern stars except that the second letter is dropped in the labelling of the spectral type (B5A becomes B5). She classified the stars for the large Henry Draper Catalogue from low dispersion objective prism plates, with hundreds of spectra on each plate. Cannon would examine the plate with a magnifying lens

225200 $23^h 59^m.2$

H.D.	DM.	R.A. 1900	Dec. 1900	Ptm.	Ptg.	Sp.	Int.	Rem.	Pl. No.	H.D.	DM.	R.A. 1900	Dec. 1900	Ptm.	Ptg.	Sp.	Int.	Rem.	Pl. No.
		m.	° ′									m.	° ′						
1	15439	59.2	−44 33	8.3	8.8	F5	7	0,3	14371b	51	12249	59.6	−52 9	7.4	8.3	Ko	7	0,3	14881b
2	10426	59.2	−54 28	8.4	9.6	Ko	3	..	14382b	52	*2786*	59.6	−70 58	*7.7*	8.5	G5	5	..	12082b
3	*7714*	59.2	−59 53	8.66	8.5	B9	4	..	42095b	53	2800	59.6	−72 0	5.64	*5.62*	B9	..	0,10	56,150
4	2345	59.2	−73 36	*9.7*	10.0	Fo	5	..	38385b	54	*908*	59.6	−81 54	*9.7*	9.7	Ao	7	..	38135b
5	6193	59.3	−11 45	9.1	*9.9*	G5	3	0,2	40911b	55	*1379*	59.7	+70 14	8.54	*8.54*	Ao	4	..	38068i
6	*19813*	59.3	−29 57	7.57	8.0	Ao	7	..	44361b	56	1994	59.7	+65 17	8.25	*8.25*	Ao	2	..	37909i
7	17802	59.3	−32 43	8.6	9.2	Ko	3	..	41067b	57	2855	59.7	+57 58	6.51	*6.34*	B3	6	0,8	37241i
8	14785	59.3	−47 38	8.9	11.2	Ko	3	..	39670b	58	4624	59.7	+43 25	8.1	*8.7*	Go	3	..	37910i
9	14331	59.3	−49 22	9.7	11.1	Ko	3	..	39670b	59	*4931*	59.7	+38 13	8.6	*8.9*	F2	3	..	37382i
10	4824	59.4	+ 1 41	9.0	*10.2*	K5	1	..	14156b	60	5057	59.7	+29 31	8.2	*8.6*	F5	2	..	37352i
11	6142	59.4	− 7 31	8.1	*8.7*	Go	5	..	14377b	61	4950	59.7	+22 43	7.87	*8.65*	G5	4	..	38102i
12	6194	59.4	−11 4	5.16	*6.23*	K2	..	2,10	56,150	62	5258	59.7	+ 5 52	9.3	*9.4*	A3	4	*1,3*	17058b
13	15492	59.4	−37 51	8.3	10.1	K5	3	0,2 R	14593b	63	6223	59.7	−10 25	10.1	*11.1*	Ko	1	..	40911b
14	4197	59.4	−65 25	*10.1*	10.9	G5	2	..	38229b	64	19818	59.7	−30 12	8.2	8.0	A2	3	..	8586b
15	1378	59.5	+69 55	8.04	*9.04*	Ko	3	..	38068i	65	*16834*	59.7	−32 56	9.6	9.2	F2	4	..	41067b
16	1679	59.5	+66 36	5.84	*6.84*	Ko	7	..	37909i	66	15392	59.7	−41 28	9.6	10.5	Go	2	..	14371b
17	*4827*	59.5	+43 0	var.	var.	Nb	1	R	37910i	67	14787	59.7	−47 9	10.3	11.8	Ko	2	..	39670b
18	4933	59.5	+41 33	6.03	*6.09*	A2	4	*2,9*	37007i	68	10424	59.7	−57 24	7.8	8.7	Ko	4	*5,3*	42095b
19	*5059*	59.5	+35 13	8.62	*9.12*	F8	2	..	37382i	69	3347	59.7	−69 24	*9.2*	9.8	Go	4	..	38229b
20	4827	59.5	+33 42	7.15	*8.15*	Ko	5	..	37382i	70	2348	59.7	−73 42	*9.6*	10.6	Ko	2	..	38385b
21	4749	59.5	+ 2 23	8.2	*9.3*	K2	3	..	14156b	71	1995	59.8	+65 58	7.8	*8.2*	F5	2	..	37909i
22	4524	59.5	− 1 37	8.92	*9.20*	Fo	4	..	14156b	72	1894	59.8	+64 52	7.50	*8.50*	Ko	4	..	37909i
23	6015	59.5	− 4 42	10.3	*10.9*	Go	1	..	14377b	73	*2103*	59.8	+64 13	7.7	*8.1*	F5	2	..	37909i
24	6240	59.5	− 8 45	8.7	*9.8*	K2	2	..	40911b	74	3141	59.8	+56 55	8.4	*9.2*	G5	1	..	38872i
25	*6511*	59.5	−12 51	9.4	*10.4*	Ko	1	..	12365b	75	3778	59.8	+51 41	9.0	*9.0*	Ao	2	..	37937i
26	6411	59.5	−16 27	8.7	*9.5*	G5	1	..	14623b	76	*5068*	59.8	+26 6	6.52	*7.59*	K2	3	..	37352i
27	6709	59.5	−20 0	9.1	10.5	K2	4	..	24596b	77	5031	59.8	+17 53	8.8	*9.8.*	Ko	2	..	38102i
28	6526	59.5	−21 28	9.4	11.1	G5	2	..	24596b	78	*6241*	59.8	− 7 50	9.4	*10.4*	Ko	1	..	40911b
29	19584	59.5	−31 44	7.8	9.6	Ko	2	..	41067b	79	6870	59.8	−17 25	8.1	*8.9*	G5	2	..	10109b
30	4399	59.5	−64 44	*10.1*	10.5	F5	2	..	38229b	80	6421	59.8	−18 44	8.9	*9.5*	Go	4	..	14623b
31	2799	59.5	−72 15	*9.0*	9.8	G5	6	..	38385b	81	*6710*	59.8	−19 58	9.1	9.6	Go	6	..	24596b
32	2347	59.5	−73 13	*9.7*	10.3	Go	6	..	38385b	82	19820	59.8	−30 49	8.6	8.0	Ao	5	..	44361b
33	2346	59.5	−73 28	7.43	7.9	F5	7	*3,8*	12082b	83	17805	59.8	−32 34	7.90	8.9	Ko	3	..	41879b
34	2133	59.5	−74 25	*8.9*	8.9	Ao	5	0,5	14357b	84	16835	59.8	−33 4	9.0	9.2	Go	4	..	41067b
35	*1600*	59.5	−76 55	*9.2*	10.0	G5	4	..	38135b	85	*10427*	59.8	−53 55	9.1	9.9	F5	3	E	14382b
36	1599	59.5	−77 26	*9.4*	10.0	Go	3	..	38135b	86	..	59.8	−69 7	..	..	G5	1	..	38229b
37	4232	59.6	+50 59	8.2	*8.3*	A2	2	..	37937i	87	*1639*	59.8	−75 56	*10.7*	11.7	Ko	1	..	38135b
38	*4405*	59.6	+46 3	9.0	*9.1*	A2	1	..	38896i	88	1248	59.8	−79 8	*10.4*	11.4	Ko	2	..	38135b
39	*4828*	59.6	+34 7	6.23	*6.79*	Go	5	0,8	37352i	89	2067	59.9	+60 46	5.87	*5.85*	B9	10	*1,6*	38872i
40	5039	59.6	+16 31	8.4	*9.2*	G5	1	..	38102i	90	4251	59.9	+46 27	8.6	*9.4*	G5	1	..	38896i
41	5094	59.6	+14 24	7.23	*7.65*	F5	5	..	38102i	91	*4549*	59.9	+45 7	7.62	*8.12*	F8	6	..	38896i
42	5257	59.6	+ 5 58	8.6	*9.6*	Ko	4	..	12386b	92	*4744*	59.9	+27 7	6.57	*7.35*	G5	4	..	37352i
43	5084	59.6	+ 0 59	8.4	*8.5*	A5	3	E	37378i	93	5168	59.9	+ 8 43	8.4	*8.7*	F2	2	..	38069i
44	4616	59.6	− 0 30	8.6	*8.9*	Fo	3	..	14156b	94	5085	59.9	+ 0 29	9.0	*9.8*	G5	3	*5,2*	13921b
45	6143	59.6	− 7 2	9.7	*10.3*	Go	1	..	40911b	95	6089	59.9	− 2 7	10.3	*11.3*	Ko	1	..	24592b
46	16896	59.6	−26 0	9.0	9.4	Go	3	..	39506b	96	6108	59.9	− 5 32	10.1	*10.7*	Go	2	..	14377b
47	16536	59.6	−27 50	9.3	9.9	Fo	1	..	23746b	97	16162	59.9	−36 35	7.61	8.3	F5	3	*3,3*	12013b
48	18953	59.6	−29 25	9.0	9.2	Ko	2	..	41067b	98	14687	59.9	−48 19	10.1	10.2	F8	4	..	39670b
49	16833	59.6	−33 5	10.5	10.4	G	1	..	41067b	99	3038	59.9	−70 46	*7.8*	8.6	G5	4	..	12082b
50	16584	59.6	−42 36	9.5	10.1	F5	3	..	14371b	100	2787	59.9	−71 3	*8.5*	8.8	F2	4	..	12082b

Fig. 20. The Last Page of the Henry Draper Catalogue. The seventh column gives the spectral type (Annals, vol. 99, p. 261, reduced).

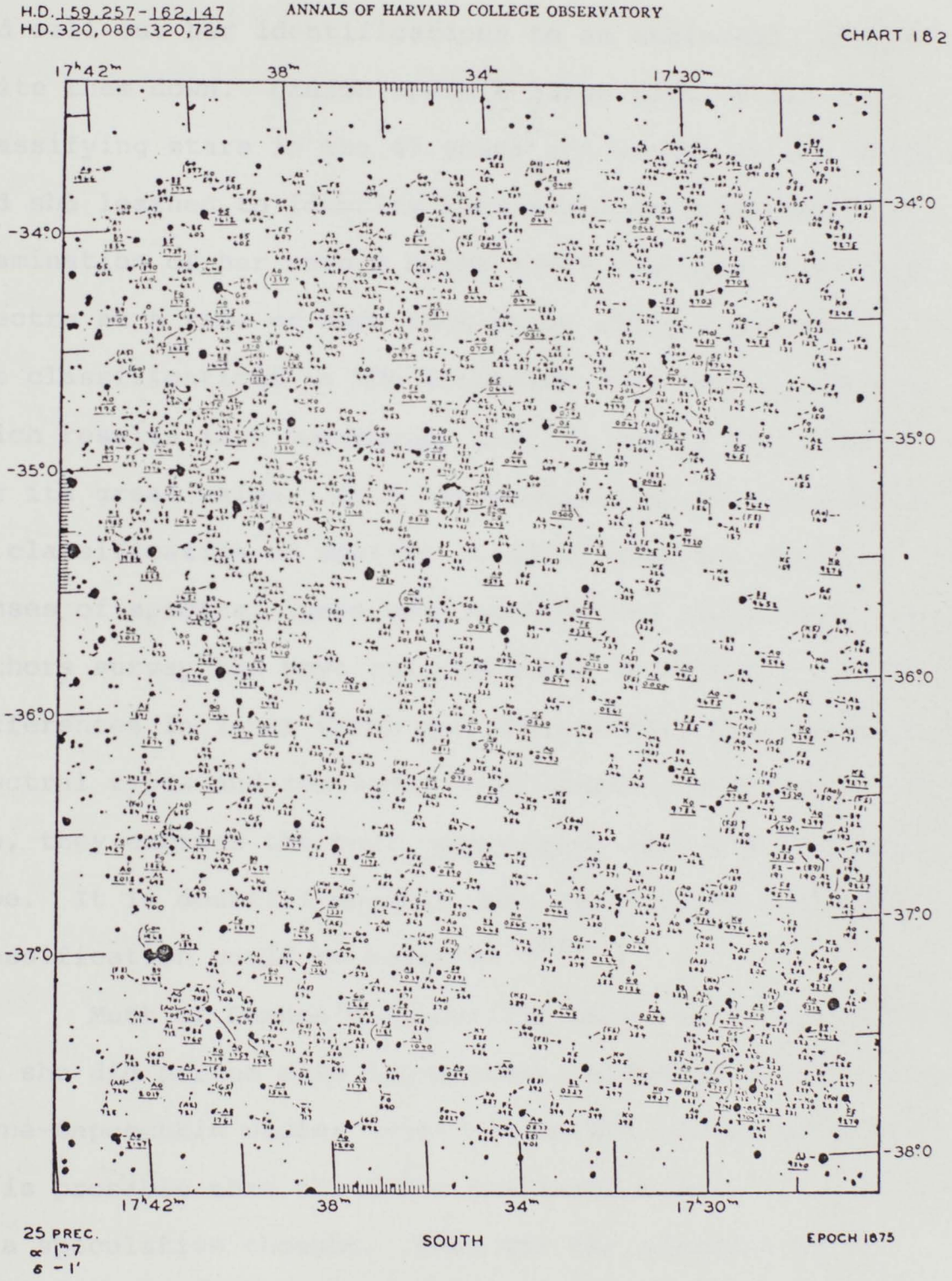

Fig. 21. The second volume of the Henry Draper Extension was published in the form of star charts with the spectral type and HD number marked on the chart. This page gives an idea of what sort of a job classifying the stars on a plate could be (Annals, vol. 112, p. 202, reduced).

and call out her identifications to an assistant, who would write them down. Cannon spent a large part of her time classifying stars in the 45 years she worked at the Observatory, and she learned to identify spectra almost instantaneously. Examination of her record books shows that she could classify spectra at a rate of more than three stars a minute.[121] All the classifications in the catalogue were done by Cannon, which results in a consistency that is one of the reasons for its great value. In a re-examination of the problem of classification of spectra in 1935, when the physical causes of spectral lines were much better understood, the authors survey the physical processes which result in the differences in lines which are the criteria for the different spectral types and conclude: "Multifarious as these criteria are, they express the most conspicuous features from type to type. It is doubtful whether more outstanding bases for classification could be selected."[122]

Much of Cannon's scientific work was classification, but she did pursue more independent investigations. Cecilia Payne-Gaposchkin wrote: "Miss Cannon was not given to theorizing; it is probable that she never published a controversial word or a speculative thought. That was the strength of her scientific work--her classification was dispassionate and unbiassed."[123] This style together with her charming personality explain why she worked more smoothly with Pickering than Maury did, but it would be unfair to give the

impression that Cannon's work was only routine. She studied variable stars as well as spectra, by observing visually as well as on plates. In 1922 she went to Arequipa, Peru, to make her own observations of southern stars.[124] Some excerpts from her diary of her stay there are revealing. On May 24, 1922, she wrote: "Worked nearly all day and 5 1/2 hours at night, running three telescopes."[125] On July 14: "Worked until 12:30 in eve. Electric lights went out and I had to climb up on high ladder to read hour angle."[126] On July 23 she wrote:

> Worked on plates in afternoon and found a suspicious object on AM plate. It appears to be a Nova! It was N.S. [not seen] on July 1, 3, vis. [visible] on July 11, 12 plates, oh, but it is so faint, probably 10 or 11 at max! Evening cloudy early and we played bridge. At 9, it cleared and I set the 10-inch at once on 17.40-36. Developed it and saw bright lines! Up and out until 12:40 all alone. Mr. B. [Solon Bailey] went to bed about 11:30.[127]

This discovery was indeed confirmed.

Cannon did not make significant theoretical investigations, but her work took a special skill. Margaret Mayall, one of her chief assistants, said that while her main work was somewhat routine, "her perception of the spectra and interpretation of them" were amazing and she had great skill at "seeing unusual things. She had wonderful eyes and she could see things that very few people would recognize until she pointed it out."[128] Cecilia Payne-Gaposchkin said of her: "Miss Cannon was a cheerful, warmhearted, affectionate, optimistic sort of person. She didn't aspire to have any scientific

Fig. 22. Cannon with the 13-inch Boyden Refractor, at Arequipa, Peru, in 1922 (The Sky 5 (1941): 3).

ideas; I don't think she ever tried to have any scientific ideas. She did her job and did it extraordinarily well."[129]

Like Fleming, Cannon was honored by the astronomical community. She belonged to, among others,the American Philosophical Society, the International Astronomical Union, and the American Astronomical Society (as the Astronomical and Astrophysical Society was renamed), of which she served as treasurer. She was also an honorary member of the Royal Astronomical Society. At Harvard she held the position of Curator of Astronomical Photographs after Fleming's retirement, but the Harvard administration was reluctant to give her a Corporation appointment. President Lowell wrote: "I always felt that Mrs. Fleming's position was somewhat anomalous, and it would be better not to make a practice of treating her successors in the same way."[130] As early as 1911 the Visiting Committee of the Observatory wrote: "It is an anomaly that, though she is recognized the world over as the greatest living expert in this line of work, and her services to the Observatory are so important, yet she holds no official position in the university."[131] In 1925 Cannon became the first woman ever to receive an honorary degree of Doctor of Science from Oxford. It was not until 1938, however, that Harvard gave her a Corporation appointment as William Cranch Bond Astronomer.

Henrietta Leavitt

The last of the famous women astronomers who did their work at Harvard before 1920 was Henrietta Swan Leavitt. The daughter of a minister, Leavitt atttended Radcliffe College and received her degree in 1892. She worked as a volunteer at Harvard Observatory in 1895-96 and did some travelling, and then spent a number of years at home in Wisconsin because of an illness that left her partially deaf. In 1902 she wrote to Pickering about continuing her work and he persuaded her to return to Cambridge. She replied to his letter

> It has proved possible for me to arrange my affairs here so that I can go to Cambridge next month and remain until the work is completed. Your very liberal offer of thirty cents an hour will enable me to do this.[132]

She worked at Harvard almost continuously from 1902 until her death in 1921. She showed great ablility in her assigned work, but Pickering gave her little opportunity to use her ability for theoretical work.

Her chief researches were in photographic photometry. The problem of determining the magnitude of a star from a photographic image is very difficult because of the complexity of the photographic process itself (the darkness of the star image on the negative is not linearly proportional to the brightness of the star), and because each telescope and type of plate gives different results on account of the differing colors of stars. Leavitt's early work was the determination of a sequence of stardard comparison stars in the region

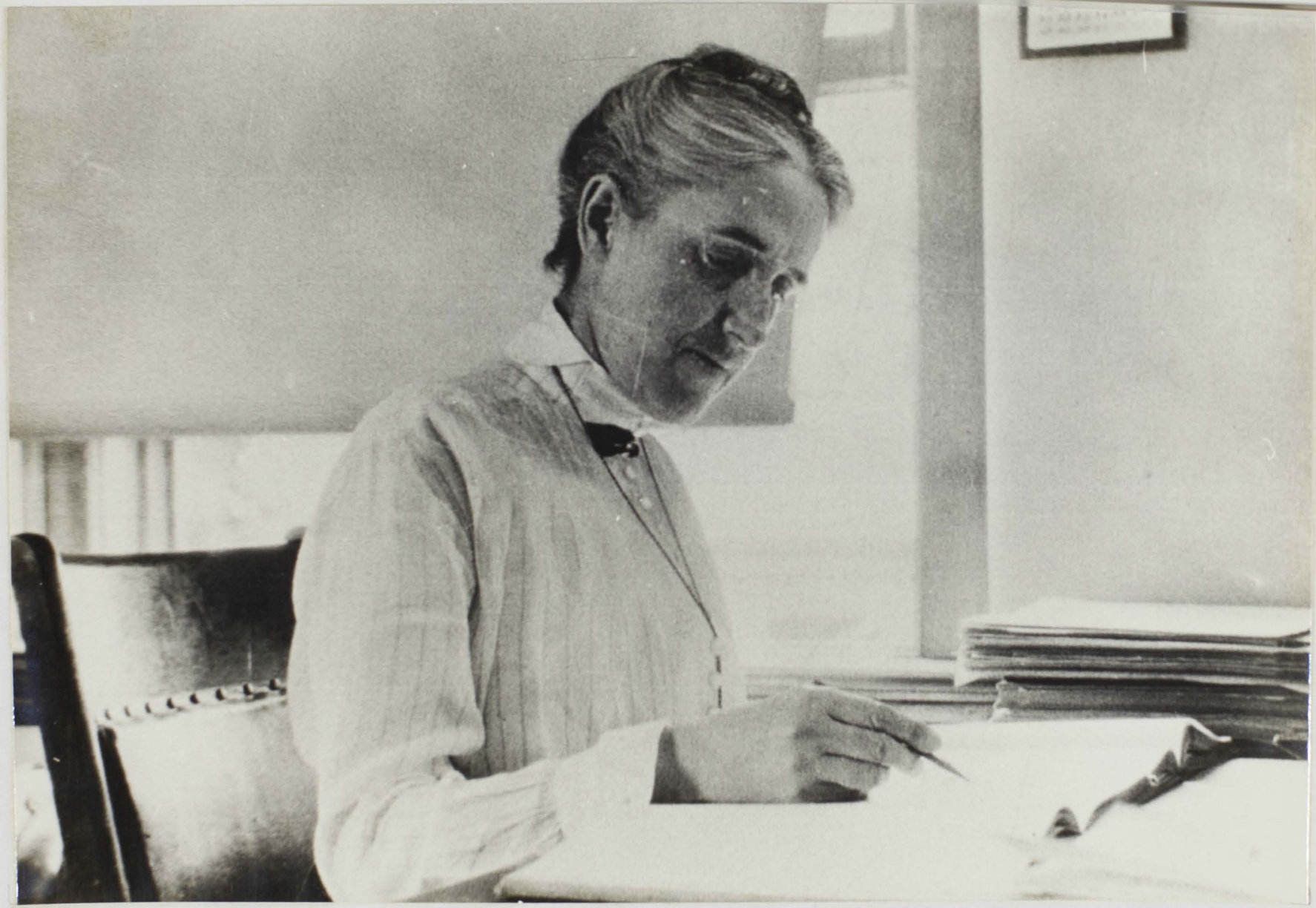

Fig. 23. Henrietta Leavitt (courtesy of Harvard College Observatory).

around the north pole. Once a sequence is determined, magnitudes can be estimated by comparing one star with another and the problem of the real meaning of the density of the image on the photographic plate can be avoided. The results of this research were published in volume 71 of the Harvard Annals. Later, Leavitt studied color indices, the difference in magnitude of a star depending on the color sensitivity of the photographic plates.[133] Pickering also gave her the difficult job of determining the corrections necessary for various telescopes.

Leavitt's investigations of variable stars were of much greater theoretical importance. She studied photographs of the Magellanic Clouds taken in Peru and discovered 1,777 new variable stars.[134] She determined the periods of a few of these and discovered a relationship between their period and their brightness. Because the stars were all in the Small Magellanic Cloud, she was able to draw the crucial conclusion that: "Since the variables are probably at nearly the same distance from the Earth, their periods are apparently associated with their actual emission of light, as determined by their mass, density, and surface brightness."[135] She did not pursue this discovery any further, and it was left to Hertzsprung to calibrate the curve of this period-luminosity relationship and to Shapley to use it in his determination of the size of the galaxy, which was one of his most important contributions to astronomy.

A recent book claims that Leavitt "recognized that her discovery could be used as an indicator of intrinsic brightness, but was prevented from pursuing the subject any further by Pickering, who believed their duty was to collect data, not interpret it."[136] The personalities and philosophies of the persons involved make this claim reasonable, but there is not enough hard evidence to prove it. It seems unlikely that Leavitt lacked the necessary scientific talent; Margaret Harwood, who worked with Leavitt, said that she had the best mind there.[137] Cecilia Payne-Gaposchkin described her: "I think she was the most brilliant of all the women. I think she was certainly someone who would have considered that duty was foremost. She wouldn't even have complained, as Miss Maury apparently did."[138] About her scientific work, Payne-Gaposchkin wrote (in an unpublished autobiography) of the complications of comparing color indices and magnitudes on plates from different telescopes:

> It is incredible that Pickering was unaware of these difficulties, or that he could have believed it possible to circumvent them. Miss Leavitt must have encountered the full effect of the same difficulties [that Payne-Gaposchkin encountered in related work] in her work on the North Polar Sequence, which called for the coordination of results from large and small instruments, and also for combination with the results that Seares was then obtaining with the reflecting telescope at Mount Wilson in his work on the fainter members of the North Polar Sequence.
>
> It was a wise decision to assign the problem of fundamental photographic photometry to Miss Leavitt, the ablest of the many able women who have appeared on the scene of Harvard Observatory. But it was also a harsh decision, which probably set back the study of variable stars for several decades, and condemned a brilliant woman to uncongenial work. Perhaps I am prejudiced.

> When I first went to Harvard, Dr. Shapley wanted me to take up Miss Leavitt's unfinished work in photographic photometry. At first I was unwilling; stellar spectra were my early love, and so they have remained. But I have seen, as Pickering must have seen, that standard photometry is the point upon which the pyramid of astronomy is balanced, and I have devoted many years to the subject, reluctant in the face of the inevitable.[139]

It is impossible to say what someone would have done if conditions had been otherwise, but Leavitt was restricted by her position as an employee expected to do assigned work, so that she could not choose the scientific problem she wished to pursue.

The stories of these four women astronomers show that the women at Harvard were limited by the same approach to research that had resulted in the hiring of large numbers of women. Because the accumulation of data was more important than theoretical research, there were opportunities for women whose talents ran toward patient and skillful cataloguing, like Fleming and Cannon, to make important contributions to science. Those women who might have had new ideas and made theoretical contributions, though, were frustrated by the work they were assigned and the lack of interest in their original investigations. Cecilia Payne-Gaposchkin said:

> I remember Miss Maury saying to me, rather sadly, "I always wanted to learn the calculus but Professor Pickering didn't wish it."... I think Pickering hired people to do a specific job and didn't want them wasting their time doing anything else.[140]

Harvard College Observatory under Pickering was dedicated to one particular style of astronomy, and women were both limited and benefited by this.

CHAPTER VII

DISCUSSION AND CONCLUSIONS

What modes of historical explanation are necessary to understand the historical material that has been presented? The contributions and actions of various people and institutions have been described. Many questions can still be asked, however, about why these people acted in the way that they did. Why did women have so many opportunities open to them and yet no more? There are many levels on which this can be explained, but only a few of them can even be attempted here. We should at least want to know, though, some of the broader interactions that affected the position of women in astronomy.

Two unexpected historical discoveries were made in the course of my research. When I started work on this thesis I thought Harvard was unique in the large number of women it employed. In fact, almost every large observatory hired women to do routine work. Harvard is different only in that it produced the most famous women. More research is required into the position of women at other observatories before Harvard's unique position can be fully understood. One explanation is that the atmosphere and the type of work being done made the hiring of women particularly convenient.

Harvard emphasized statistical and comparative study of stars in order not to be overshadowed by the new investigations of the structure of the galaxy and the universe possible with the more powerful telescopes in the midwest and west. The research Harvard chose to stress required tremendous amounts of routine work, which women were hired to perform, but it was a kind of routine work which had some potential for creative investigation.

The other unexpected discovery made in the course of this research was the importance of the role of the women's colleges. The dedication of their professors of astronomy to research and to rigorous teaching was a surprise to me. Before dependable conclusions can be drawn, of course, the opportunities and actions of men in similar situations need to be studied in more detail. Astronomy seems an unlikely science for a women's college to emphasize because it requires expensive equipment and being outside at night. It had a romantic and popular appeal, however, and perhaps the presence of Maria Mitchell as a role model made it seem more acceptable. The development of a career structure made the women's colleges important. The professors had an impact on the position of women in observatories because they could find their students jobs and convince astronomers that their students were desirable employees.

The broadest generalization of the historical problem is that astronomers were surprisingly willing, considering

attitudes towards women at the time, to accept women as employees and to accept the talented women at Harvard and other observatories and the professors at the women's colleges as colleagues. This willingness to accept women needs explanation on a deeper level than the type of work being done at a particular institution or the influences of popular beliefs and individuals at other institutions.

Astronomers accepted women as employees at least in part for economic reasons. Women performed tedious work with great patience for low wages. The character of astronomy at the time, the emphasis placed on data collection, resulted in unusual opportunities for women. The semi-independent stuatus of observatories helped make the hiring of women possible. Women could not easily become official members of the staff at men's colleges, but this did not hinder a woman like Annie Cannon. She held the position of curator of astronomical photographs for many years and was acclaimed by astronomers all over the world before Harvard University gave her a corporation appointment. Also, if the observatories had been tied more closely to universities there might have been more students around to do some of the routine work that women performed, particularly at schools whose students were less rich than Harvard's. Whatever the specific reasons, the importance of the semi-independent status of observatories is supported by the fact that the other sciences which had a large percentage of women--

botany, zoology, and anthropology (see appendix A)--were associated with museums, which had a semi-independent status similar to observatories. Little information on women in other sciences in this time period is available except for the statistical study discussed in the first part of appendix A and a few old biographies. It can only be hoped that this study will inspire others.

I believe, although I do not claim that the evidence is conclusive, that talented women at the observatories were accepted as colleagues because they performed, and performed well, a certain kind of work that was considered women's work. Probably men (and women) developed their assumptions about what was women's work from the sort of work they saw the ordinary women employees doing. Women executed projects set up for them by others; the talents for which they received praise were not originality or scientific thinking but patience and keen perception. Women with the appropriate talents found great opportunities open to them, but those whose talents lay elsewhere found that these opportunities were restrictions. Williamina Fleming and Annie Cannon were rightly praised for their catalogues and their discoveries of unusual stars, but Antonia Maury and Henrietta Leavitt received far less recongnition for their contributions to theoretical understanding. It was an age in which theoretical work was not stressed in American astronomy, but others became famous for completing the theories for which these women laid the groundwork.

The women at the women's colleges undertook what was in essence the same sort of women's work, and for this they too were accepted by the men as colleagues. The work of the professors at the women's colleges required the same talents, patience and keen perception, as the work of the notable women at the observatories. The professors at the women's colleges observed the positions of comets and asteroids and the brightness of variable stars, all small parts of large compilations of data planned by someone else. After reading letters by these women about their research I cannot believe that the fault lay in lack of interest or effort. Yet they were no more successful in being full participants in science, by modern definitions, than most of the women at the observatories; their work was no more original. Perhaps this was the fault of the restrictions caused by being at a small college where their primary responsibility was teaching. Possibly, though, they could have chosen more creative research to work on in the time they could spare. They chose to work on comets, asteroids, and variable stars because that was the advice their male colleagues gave them. This advice was no doubt given with the best intentions, but the research suggested conformed to the stereotypes of women's work in astronomy.

I do not claim that men were not restricted in similar ways, but only that women were more limited than men. The recent professionalization of astronomy resulted in

an emphasis on observational rather than theoretical work. The popular conception of the role of an astronomer was that he worked in an observatory and observed the stars. Because astronomers were not yet in a secure professional position they could not easily go against the popular conceptions of their job. Men astronomers also had to do what they were told; when William H. Wright was hired by Lick Observatory the director told him to study ultraviolet spectroscopy, so that is what he did. Not until many years later, when he became the director himself, could he pursue his original interest in proper motion. The difference is that even if the men were given as specific a problem to work on as the women were (which I doubt but do not have the evidence to prove), the men always had the possibility of becoming the director of a research observatory, which the women did not have.

The next layer of explanation is the question of how and why women were limited in these ways. The women at observatories were restricted in simple ways; if they wanted to be paid they had to do what they were told to do. They were hired to perform routine work, and so that is what they did. If they could afford to, they could work as volunteers, as Maury did, but it is hard to pursue difficult and original work with little encouragement. The women at the women's colleges were limited by equipment and teaching load, as men were also in similar situations, and also by

the kind of problems they chose to work on. Why women were limited is a more difficult question. Most fundamentally, perhaps, they were restricted by the beliefs of the society that they lived in. Expectations of women resulted from the widespread belief that women were incapable of original thought. Institutions tend to become solidified in such a way that it is difficult for people to do things that are not expected of them. The institutional position that women gained in astronomy gave them some opportunities, but prevented them from being independent, creative scientists.

There are further levels of analysis that I have not even been able to start to pursue within the scope of this thesis. There is the question of cumulative disadvantage, of how the women were limited by influences on them before they became professional astronomers. Disadvantage can be direct, for a woman like Maury who never had an opportunity to learn the calculus, or indirect, for women who were never taught to value or use their theoretical insight. In addition, what was the effect of Victorian ideas about women on the women themselves? Women were probably limited as much by how they felt about their own work as by discrimination and pressures from outside. What we have seen about the personalities of some of the women is the starting point for an understanding of this.

Further analysis of influences external to science is necessary not only for an understanding of the effects

of these influences on the way the women viewed their work but also for other levels of explanation. The social and intellectual structure of science is influenced in more ways by the outside society than have been even mentioned here, particularly when what is considered is so large a part of society as the position of women. I had hoped to be able to treat external influences in more depth than has been given. It proved to be very difficult, however, to understand the attitudes of the society towards women and the ways in which this affected science in sufficient depth to be able to analyze in any detail how astronomy was influenced in this particular case. The historical material on the position and scientific work of women astronomers had to be given first priority because it is only through an understanding of this that the larger subject can be approached.

For a study in the social structure of science the same sort of further research is necessary. I have concentrated on the question of how the position of women scientists influenced the scientific work that they did because I believe that this is a problem in the sociology of science that is both important and accessible to historical study. The sociology of science seeks to explain the domain from the outside society to the development of scientific ideas. What explanations I have given for the case of the women astronomers are in the internal half of this spectrum, and study of the external half is as necessary to develop a

complete picture. The results of what I have done are not conclusive and broad enough to allow broad generalizations, but I hope they will provide ideas for future work.

Finally, though, we must not forget that unusual opportunities were open to women in astronomy in this period, and they did make important contributions to science. That women were accepted as scientists at all, even if in limited ways, shows that American intellectuals in the late nineteenth and early twentiety centuries were more open-minded about intellectual and profesional opportunities for women than people today often think. I have claimed that women astronomers were prevented from doing original scientific work by the expectations and institutional framework that surrounded them, but Annie Cannon's catalogue of the spectral types of stars is of more value today as a collection of data than any number of creative and original theories that are now outmoded. The combination of the availability of scientific training in the women's colleges and of jobs for women in the large observatories has resulted in a large amount of valuable work, even if it was not all they had the potential for, done by women in astronomy for the late nineteenth century right up to the present.

ENDNOTES

Notes to pp. 1-14

[1]For sources and further information on this and later references to known women astronomers see appendix A.

[2]Solon I. Bailey, The History and Work of Harvard Observatory 1839 to 1927 (New York: McGraw-Hill Book Co., 1931), p. 116.

[3]For further information on the growth and support of astronomical institutions in the nineteenth century see: Howard S. Miller, Dollars for Research: Science and Its Patrons in Nineteenth-Century America (Seattle, Washington: University of Washington Press, 1970), particularly chapter 5.

[4]1848 was the date of the first women's rights meeting, called by Elizabeth Candy Stanton in Seneca Falls, New York.

[5]June Sochen, Herstory: A Woman's View of American History (New York: Alfred Publishing Co., 1974), p. 181.

[6]What this means is that since 1930 the number of men receiving Ph.D.s has grown faster than the number of women receiving Ph.D.s. In physics and astronomy women recieved 5.9 percent of all Ph.D.s in 1920-29 and 2.2 percent of all Ph.D.s in 1960-69. See Evelyn Fox Keller, "Women in Science: An Analysis of a Social Problem," Harvard Magazine 79 (October 1974):17.

[7]Bessie Z. Jones and Lyle G. Boyd, The Harvard College Observatory: The First Four Directorships, 1839-1919 (Cambridge, Mass.: Belknap Press of Harvard University Press, 1971), p.385.

[8]Helen Wright, Sweeper in the Sky: The Life of Maria Mitchell, First Woman Astronomer in America (New York: Macmillan Co., 1950), p. 71.

[9]Maria Mitchell, "Annual Report, June 12, 1868" (in the form of a handwritten letter), Vassar College Archives, Poughkeepsie, N.Y.

[10]Maria Mitchell, "Annual Report, June 15, 1869," Vassar College Archives, Poughkeepsie, N.Y.

Notes to pp. 14-20

[11]Maria Mitchell, "Annual Report, 1887-88," Vassar College Archives, Poughkeepsie, N.Y.

[12]Phebe Mitchell Kendall, ed., Maria Mitchell: Life, Letters, and Journals (Boston: Lee and Shepard Publishers, 1896), p. 179.

[13]Maria Mitchell, "The Collegiate Education of Girls," paper read at the Congress of the American Association for the Advancement of Women in October 1880 and published in Anna C. Brackett, ed., Women and the Higher Education (New York: Harper and Brothers, 1893), p. 69.

[14]Professor T. H. Safford at the Dearborn Observatory of the old University of Chicago.

[15]Gertrude Mead to Mary Whitney, Sept. 29, 1870, Vassar College Archives, Poughkeepsie, N.Y.

[16]Caroline E. Furness, "Mary W. Whitney," Popular Astronomy 30 (1922): 601-2.

[17]Mary W. Whitney, "Annual Report, 1906-7," Vassar College Archives, Poughkeepsie, N.Y.

[18]Mary W. Whitney, "Annual Report for 1896-7," Vassar College Archives, Poughkeepsie, N.Y.

[19]Mary W. Whitney, Introduction to Catalogue of Stars Within One Degree of the North Pole, Publications of the Vassar College Observatory, No. 1, by Caroline E. Furness (Poughkeepsie, N.Y.: 1900), pp. iii-iv.

[20]See appendix A for discussion and further details.

[21]Furness, "Mary W. Whitney," 31 (1923): 26-7.

[22]Frank Schlesinger to Caroline Furness, June 9, 1903, Vassar College Archives, Poughkeepsie, N.Y.

[23]George E. Hale to Mary Whitney, June 12, 1901, Vassar College Archives, Poughkeepsie, N.Y.

[24]Simon Newcomb to Mary Whitney, Nov. 27, 1905, Vassar College Archives, Poughkeepsie, N.Y.

[25]George A. Campbell to Vassar Department of Astronomy, Many 25, 1912, Vassar College Archives, Poughkeepsie, N.Y.

Notes to pp. 23-31

[26]See letter quoted in Kendall, Maria Mitchell, p. 20.

[27]Mary E. Byrd, "Anna Winlock," Popular Astronomy 12 (1904):

[28]The proof that Mrs. R. T. Rogers was William Roger's wife is not indisputible, but she must have been a close relative if not his wife because she wrote notes to the observatory from his address when he was sick to say that he would not be in.

[29]William A. Rogers to C. W. Eliot, Nov. 23, 1875, Observatory Correspondence (hereafter abbreviated HCO Corr.), UA V 630.17, group 2, folder Ri-Rom, Harvard Archives, Cambridge, Mass.

[30]C. W. Eliot to Arthur Searle, Nov. 27, 1875, HCO Corr. UA V 630.17, group 1, folder Harvard President #2.

[31]Margaret Harwood, interview held in Cambridge, Mass., Dec. 1, 1976.

[32]Selina C. Bond to E. C. Pickering, July 5, 1887, HCO Corr. UA V 630.17.5, group 1, folder Selina C. Bond.

[33]For a more detailed description of the founding of the Draper Memorial see Jones and Boyd, Harvard College Observatory, pp.211-245.

[34]Helen L. Reed, "Women's Work at the Harvard Observatory," New England Magazine 6 (1892):174-5.

[35]Mabel C. Stevens to E. C. Pickering, Sept. 8, 1887, HCO Corr. UA V 630.17, group 1, folder Sn-Sten.

[36]Annie E. Masters to E. C. Pickering, June 23, 1884, HCO Corr. UA V 630.17, group 1, folder Mart-Mat.

[37]Florence Cushman to E. C. Pickering, Jan. 31, 1888, HCO Corr. UA V 630.17, group 1, folder Cre-Cun.

[38]Mary H. Cooke to E. C. Pickering, Feb. 1, no year, HCO Corr. UA V 630.17, group 1, folder Cla-Cly.

[39]Imogen W. Eddy to E. C. Pickering, July 11, no year, HCO Corr. UA V 630.17, group 2, folder Ea-Ed.

[40]Arthur Searle to N. O. Smith, Aug. 23, 1889, HCO Corr. UA V 630.14, letter book A9, p. 8.

Notes to pp. 31-40

[41]Mrs. Fleming, who was then supervising the work of eight other women, earned a salary of $1200 a year in 1892. C. W. Eliot to E. C. Pickering, March 1, 1892, HCO Corr. UA V 630.17, group 1, folder Harvard President #2.

[42]W. P. Fleming to Miss Hume, May 11, 1906, HCO Corr. UA V 630.14, letter book A17, p. 654.

[43]William A. Rogers to C. W. Eliot, Nov. 23, 1875, HCO Corr. 630.17, group 2, folder Ri-Rom.

[44]This is the salary Mary S. Wagner claims she could get. Mary S. Wagner to E. C. Pickering, May 15, 1893, HCO Corr. UA V 630.17, group 1, Folder Wad-Way #2.

[45]Bureau of the Census, Statistics of Women at Work, based on the 12th census in 1900 (Washington D.C.: Government Printing Office, 1907).

[46]U.S. Bureau of Labor Statistics, Summary of the Report on Condition of Woman and Child Wage Earners in the United States (Washington D.C.: Government Printing Office, 1916) p. 25.

[47]Joseph Winlock to C. W. Eliot, Nov. 10, 1887, HCO Corr. UA V 630.14, letter book A2, p. 475.

[48]C. W. Eliot to E. C. Pickering, Dec. 1, 1887, HCO Corr. UA V 630.17, group 1, folder Harvard President #2.

[49]The people and developments at the individual women's colleges will be considered in more detail in the next chapter.

[50]Frank Schlesinger to Caroline Furness, June 9, 1903, Vassar College Archives, Poughkeepsie, N.Y.

[51]Emily E. Dobbin, "The Orbit of the Fifth Satellite of Jupiter," Astrophysical Journal 24 (1904-5): 83.

[52]J. B. Oke was kind enough to send Professor Gingerich a copy of the memo of March 26, 1965 which first officially allowed women to observe at Mount Wilson.

[53]Jennie Lasby, "Spectroscopic Observations of the Rotation of the Sun," Popular Astronomy 19 (1911): 89-97, and "The 100-inch Telescope at Mount Wilson," Popular Astronomy 25 (1917): 649-51.

[54]Janet T. Howell, "The Effect of and Electric Field on the Lines of Calcium and Lithium," Astrophysical Journal 44 (1916): 87-102.

[55]Etta M. Eaton, Elements and Ephemerides of various comets, Astronomical Journal 26 (1908-11): 14, 62; Eleanor A. Lamson, Elements and Ephemerides of comets and minor planets, Astronomical Journal 25 (1905-8): 34, 60, 168, 190; vol. 26 (1908-11): 54.

[56]Anne P. McKenney, "What Women Have Done for Astronomy in the United States," Popular Astronomy 12 (1904): 175.

[57]Furness, "Mary Whitney," 31 (1923): 27.

[58]Margaretta Palmer, "The Yale Index to Star Catalogues," Astronomical Journal 30 (1916-17): 166; Comet Orbits, vol. 31 (1917-18): 189; vol. 32 (1919-20): 30; vol. 34 (1921-23): 84.

[59]Benjamin Boss, History of the Dudley Observatory 1852-1956 (Albany, N.Y.: The Dudley Observatory, 1968), pp. 79-80.

[60]Anna D. Lewis, who received a B.A. from Carleton College in 1889 and a Ph.D. in 1896, described the history of the program there:

> "When I was in College (1885-89), Dr. W. W. Payne was head of the Goodsell Observatory for which he had great ambition, hoping to make it a School of Astronomy with a graduate course leading to the doctor's degree. By 1908 six people, three men and three women, had finished the course. Then a new president came to the College, who did not know (or care) about Professor Payne's plans, and the course was discontinued and Dr. Payne retired."

Quoted in Walter Crosby Eells, "American Doctoral Dissertations on Mathematics and Astronomy Written by Women in the Nineteenth Century," Mathematics Teacher 50 (1957): 375.

[61]I know very little about the status of women in astronomy in other countries, but another American woman, Dr. Dorothy Klumpke-Roberts, headed the photographic department at the Paris Observatory.

[62]Furness, "Mary W. Whitney" 31 (1923): 28. The same article, p. 31, tells another story in the same vein:

> "In the winter of 1902 a pleasant incident happened which gave a final status to the position of women in the American Astronomical Society. The annual meeting was held in Washington in connection with the AAAS and

it was planned to have a dinner. Notification blanks were sent out, and after some hesitation the invitation was refused with an intimation that perhaps the presence of women was not desired, that being the custom in several of the other scientific societies. A prompt response came from Professor Newcomb, the president, which settled the question permanently.

'I am much disappointed to notice that although you hope to be here at our meeting, you do not propose to join in the dinner. Possibly you may be under a misapprehension, supposing that the dinner is only for the men of the society. Permit me, therefore to assure you that all members are equal, and that we should like very much to have our lady members with us.'"

[63]Sally Gregory Kohlstedt, The Formation of the American Scientific Community: The American Association for the Advancement of Science 1848-1860 (Urbana, Illinois: Univ. of Illinios Press, 1976), p. 103.

[64]Arthur Auwers to Mary W. Whitney, March 24, 1897, Vassar College Archives, Poughkeepsie, N.Y.

[65]Mary S. Wagner to E. C. Pickering, May 15, 1893, HCO Corr. UA V 630.17, group 1, folder Wad-Way #2.

[66]E. C. Pickering to M. S. Wagner, May 18, 1893, HCO Corr. UA V 630.14, letter book A11, p. 635.

[67]M. S. Wagner to E. C. Pickering, May 22, 1893, HCO Corr. UA V 630.17, group 1, folder Wad-Way #2.

[68]Arthur Searle to M. S. Wagner, May 23, 1893, HCO Corr. UA V 630.14, letter book A11, p. 646.

[69]M. S. Wagner to A. Searle, May 26, 1893, HCO Corr. UA V 630.17, group 1, folder Wad-Way #2.

[70]Ibid., M. S. Wagner to A. Searle, Dec. 11, 1893.

[71]Ibid., M. S. Wagner to A. Searle, Dec. 19, 1893. At least a few years later there were no strict rules about women using the telescopes. Pickering wrote to Annie Cannon, then at Wellesley: "One or more telescopes will also be available for the observations on variable stars which you wish to make." E. C. Pickering to A. J. Cannon, Jan. 15, 1896, HCO Corr. UA V 630.14, letter book A13, p. 189.

[72]M. S. Wagner to A. Searle, Feb. 14, 1894, HCO Corr. UA V 630.17, group 1, folder Wad-Way #2.

[73]E. C. Pickering to Mary W. Whitney, Mar. 3, 1896, HCO Corr. UA V 630.14, letter book A13, p. 242.

[74]See appendix A for a description of the methods and assumptions used in arriving at these figures.

[75]Caroline Furness, Observations of Variable Stars Made During the Years 1901-12 Under the Direction of Mary W. Whitney, Publications of the Vassar College Observatory, No. 3 (Poughkeepsie, N.Y.: 1913), p. 216-17.

[76]Except for her observations of the surface features of Jupiter and Saturn and the determination of the longitude of the Vassar College Observatory in 1877 by exchange of clock signals with Harvard.

[77]Furness, "Mary W. Whitney," 30 (1922): 605-8; 31 (1923): 25.

[78]Ibid., p. 26.

[79]Personal communication.

[80]The dates are 1868-1903 according to the Dictionary of Scientific Biography, s.v. "Charles Augustus Young" by Richard Berendzen and Richard Hart.

[81]Quoted in a memorial for Elizabeth M. Bardwell, Mount Holyoke Archives, South Hadley, Mass.

[82]Anne Sewell Young, "The Leonids," Popular Astronomy 4 (1896-97): 498-99; "Elliptic Elements of Comet g1896," Astronomical Journal 17 (1896-97): 192.

[83]Alice H. Farnsworth, "Astronomy at Mount Holyoke" (short typewritten paper dated July 3, 1950), Mount Holyoke Archives, South Hadley, Mass.

[84]At least two other candidates were considered: Winifred Edgerton, a graduate of Wellesley and student at Columbia, and Anna Winlock, a computer at Harvard. The position was as director of the observatory but not professor of astronomy; Mary Byrd mentioned in a letter:"It is, I understand, contrary to the traditions of this institution to give any woman the title and pay of professor." Mary Byrd to E. C. Pickering, Nov. 24, 1888, HCO Corr. UA V 630.17, group 1, folder Bua-By.

Notes to pp. 57-60

[85]Mary Byrd, "Report of Smith College Observatory for the year 1891-2" (handwritten), Smith College Archives, Northampton, Mass.

[86]Mary Byrd, "Report of Smith College Observatory for the year 1892-3," Smith College Archives, Northampton, Mass.

[87]Mary E. Byrd to E. C. Pickering, June 2, 1905, HCO Corr. UA V 630.17, group 2, folder Bua-By.

[88]Mary Byrd and Harriet W. Bigelow, "Observations of Comets," Astronomische Nachrichten 169 (1905): 191.

[89]Byrd retired to her home in Kansas, where she spent most of the rest of her life, writing occasional articles on the teaching of astronomy. In a letter to a friend written 15 years after her retirement, she wrote:

> "It is almost forty years to the month since I met my first class in astronomy, at Wabash High School, Indiana. Never was the outlook darker in all that time for practical elementary astronomy. Ah, I have worked hard, given up so much to do my best to bring in better ways of teaching, and now the conviction comes home that I have failed. I should like to write just one more article, a scathing review of the unutterable indifference of astronomers, most of them, to the teaching of the elements of their science. I could do it too, I could say things in a way to make even the astronomers in the big observatories 'sit up and take notice' but I don't suppose I shall. It would mean hard work and probably would not do much good. Then too I am too kindhearted really to enjoy more than the first few sentences."

Mary E. Byrd to Mary Murray Hopkins, Oct. 12, 1920, Smith College Archives, Northampton, Mass.

[90]Harriet W. Bigelow, "Declinations of Certain Circumpolar Stars," Astronomical Journal 24 (1904-5): 102. Comet Observations, vol. 25 (1905-8): 183; vol. 26 (1908-11): 68; vol. 27 (1911-13): 46, 108; vol. 28 (1913-15): 41; vol. 29 (1915-16): 139.

[91]This was unusual, astronomy at Harvard College was taught by professors of mathematics and astronomy who were not connected with the Observatory.

[92]Sarah F. Whiting, "History of the Physics Department of Wellesley College from 1878 to 1912" (typewritten paper), p. 23, Wellesley College Archives, Wellesley, Mass.

[93]Cecilia Payne-Gaposchkin, interview held in Cambridge, Mass., March 7, 1977.

[94]Edward C. Pickering, A Plan for Securing Observations of the Variable Stars (Cambridge, Mass.: John Wilson, 1882), p. 4.

[95]Annie J. Cannon and Edward C. Pickering, The Henry Draper Catalogue, Annals of the Harvard College Observatory, vol. 91 (1918), p. iii.

[96]Rumor has it that the father of Fleming's son was Pickering, but there is no proof of this. The recognition that Fleming did receive shows that she had Pickering's support, for whatever reason

[97]Dorrit Hoffleit, interview held at Yale University, New Haven, Conn., Nov. 11, 1976.

[98]E. C. Pickering, Official Memorial for Williamina Fleming, in a scrapbook of notices on her death, HUG 1396.5, Harvard University Archives, Cambridge, Mass.

[99]E. C. Pickering to Anna P. Draper, Dec. 31, 1886, quoted in Lyle G. Boyd, "Mrs. Henry Draper and the Harvard College Observatory: 1883-1887," Harvard Library Bulletin 17 (1969): 95.

[100]E. C. Pickering, Preparation and Discussion of the Draper Catalogue, Annals of the Harvard College Observatory, vol. 26 (1891), p. xvii.

[101]Annie J. Cannon, "Williamina Paton Fleming," Astrophysical Journal 33 (1911): 314.

[102]Harriet Richardson Donaghe, "Photographic Flashes from Harvard Observatory," Popular Astronomy 6 (1898): 450.

[103]According to Cecilia Payne-Gaposhkin, interview held in Cambridge, Mass., March 7, 1977.

[104]Cannon, "Williamina Paton Fleming," p. 316.

[105]Antonia Maury and E. C. Pickering, Spectra of Bright Stars Photographed with the 11-Inch Draper Telescope as Part of the Henry Draper Memorial, Annals of the Harvard College Observatory, vol. 28, part 1 (1897), p. 4.

[106]Antonia C. Maury to E. C. Pickering, May 7, 1892, HCO Corr. UA V 630.17.7, folder Antonia Maury.

[107]E. C. Pickering to Antonia Maury, May 11, 1892, HCO Corr. UA V 630.14, letter book A11, p. 137.

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[108]The statement appears in the letter book as a letter from Pickering to Maury agreed to and signed at the bottom by Maury. It reads:

> "In order to provide satisfactorily for the completion and publication of your work on the stellar spectra photographed here, I understand that you will be ready on or before December 1, 1893, to deliver, to the observatory, the papers which contain the work, with a statement of the results prepared for publication so far as practicable; this statement to be complete, if possible, but if any further work upon it should be necessary, it is to be completed by anyone here who may be put in charge of it, and to whom you will furnish such explanations and such information as may be needed for the purpose."

E. C. Pickering to Antonia Maury, April 3, 1893, HCO Corr. UA V 630.14, letter book All, p. 569.

[109]Mytton Maury to E. C. Pickering, Dec. 19, 1894, HCO Corr. UA V 630.17, group 1, folder Mau-Maz.

[110]Antonia Maury to E. C. Pickering, Dec. 21, no year, HCO Corr. 630.17.5, group 1, folder Antonia Maury.

[111]Dorrit Hoffleit, interview held at Yale University, New Haven, Conn., Nov. 11, 1976.

[112]Cecilia Payne-Gaposchkin, interview held in Cambridge, Mass., March 7, 1977.

[113]Ejnar Hertzsprung to E. C. Pickering, July 22, 1908, HCO Corr. UA V 630.17.8, folder Hertzsprung.

[114]One major paper of the subject was: Antonia Maury, "The Spectral Chages of Beta Lyrae," Annals of the Harvard College Observatory, vol. 84, p. 207.

[115]Helen Sawyer Hogg, interview held in Dunstable, Mass., Aug. 16, 1976.

[116]Dorrit Hoffleit, "Antonia Maury," Sky and Telescope 11 (1952): 106.

[117]Cecilia Payne-Gaposchkin, interview held in Cambridge, Mass., March 7, 1977.

[118]Annie J. Cannon, Diary, entry for Sept. 21, 1885, private collection of Margaret Mayall.

[119]Leon Campbell, "Annie Jump Cannon," Popular Astronomy 49 (1941): 345.

Notes to pp. 78-87

[120]Annie J. Cannon and E. C. Pickering, Spectra of Bright Southern Stars Photographed with the 13-inch Boyden Telescope as Part of the Henry Draper Memorial, Annals of the Harvard College Observatory, vol. 28, part 2 (1901), p. 131.

[121]Owen Gingerich, "Laboratory Exercises in Astronomy--Spectral Classification," Sky and Telescope 28 (1964): 82.

[122]H. N. Russel, Cecilia Payne-Gaposchkin, and D. H. Menzel, "The Classification of Stellar Spectra," Astrophysical Journal 81 (1935): 107.

[123]Cecilia Payne-Gaposchkin, "Miss Cannon and Stellar Spectroscopy," The Telescope 8 (1941): 63.

[124]And also to get out from under foot of the new director, Harlow Shapley.

[125]Annie J. Cannon, Diary, entry for May 24, 1922, private collection of Margaret Mayall.

[126]Ibid., June 14, 1922.

[127]Ibid., June 23, 1922.

[128]Margaret Mayall, interview held in Cambridge, Mass., Dec. 8, 1976.

[129]Cecilia Payne-Gaposchkin, interview held in Cambridge, Mass., March 7, 1977.

[130]A. Lawrence Lowell to E. C. Pickering, Oct. 11, 1911, HCO Corr. UA V 630.17.5, group 2, folder Harvard President's Office.

[131]Report of the Committe to Visit the Astronomical Observatory of Harvard College, quoted in "Minor Notes," Popular Astronomy 20 (1912): 684.

[132]Henrietta S. Leavitt to E. C. Pickering, May 21, 1902, HCO Corr. UA V 630.17.5, group 2, folder H. S. Leavitt.

[133]See for example: Henrietta Leavitt to E. C. Pickering, April 17, 1913, HCO Corr. UA V 630.17.5, group 2, folder H. S. Leavitt.

[134]While she was in Peru (April 20, 1922), Annie Cannon wrote in her diary: "Magellanic Cloud (Great) so bright. It always makes me think of poor Henrietta. How she loved the 'Clouds.'"

Notes to pp. 87-89

[135]Edward C. Pickering, "Periods of 25 Variable Stars in the Small Magellanic Cloud," Harvard College Observatory Circular no. 173.

[136]Richard Berendzen, Richard Hart, and Daniel Seeley, Man Discovers the Galaxies (New York: Science History Publications, a division of Neale Watson Academic Publications, 1976), p. 22.

[137]Margaret Harwood, interview held in Cambrige, Mass., Dec. 1, 1976.

[138]Cecilia Payne-Gaposchkin, interview held in Cambridge, Mass., March 7, 1977.

[139]Cecilia Payne-Gaposchkin, Unpublished Autobiography, courtesy of the author.

[140]Cecilia Payne-Gaposchkin, interviewed by Owen Gingerich in Cambridge, Mass. on March 5, 1968, courtesy of the Niels Bohr Library of the American Institute of Physics.

APPENDIX A

STATISTICAL STUDY

The goal of this appendix is to explain the methods used to get results given in the body of this thesis and to give results in tabular form for clarity. Full results are given not because they are trustworthy enough to be the sole support of any claim, but rather because they raise possibilities that should be investigated. Three different topics are considered: (1) Margaret Rossiter's study of women scientists in different fields in the early 20th century; (2) an analysis of the careers of women astronomers who turned up in the course of my study; and (3) figures on the number of papers published by women in the various astronomical journals.

Comparison of Women in Different Fields

The most available source of data for statistical studies of women scientists in this period is American Men of Science: A Biographical Directory,[1] the first three editions of which were published in 1906, 1910, and 1921. J. McKeen Cattell (the editor of Science), who assembled this directory, included all members of certain scientific societies and selected scientists listed in university catalogues and other reference books or who had published

scientific papers. This probably resulted in an under-representation of women (particularly because they were unlikely to be listed in the catalogues of all-male universities where many of them worked), but the percentage of those included who are women is still 3.6 percent in the first edition, 3.5 percent in the second, and 4.8 percent in the third.[2] Margaret Rossiter studied "Women Scientists in America Before 1920" by analysing the careers of the 504 women listed in these three editions.[3] She found that of the scientists listed in the first three editions of American Men of Science:

2.5 percent of the chemists were women
2.6 percent of the physicists
3.8 percent of the geologists
4.3 percent of those in medical sciences
6.3 percent of the mathematicians
6.4 percent of the astronomers
7.7 percent of the anthropologists
8.9 percent of the zoologists
9.4 percent of the botanists, and
22.8 percent of the psychologists.[4]

Rossiter's material on career patterns provides some basis on which to compare the careers of the women astronomers with other women scientists. Of the 21 women astronomers Rossiter found in American Men of Science, 12 had bachelors degrees: five from Vassar, three from Smith, two from Radcliffe, and one each from Wellesley and the University of Michigan. The ten colleges which produced the most listed women scientists in all fields are (in order): Wellesley (with 36), Vassar, Smith, Mount Holyoke, Cornell, University of Michigan, Bryn Mawr, University of Chicago,

Barnard, and the University of Pennsylvania (with 12).[5] Twenty of the 21 women astronomers (95 percent) held jobs in universities, 10 as professors and 10 in observatories, compared with 68 percent of all the women scientists. Five of the women astronomers (24 percent) had earned Ph.D.'s, compared with an average of 63 percent of women scientists in all fields. Two of the women astronomers (9.5 percent) were married (although at least one of these was separated from her husband), compared to an average of 19.4 percent.[6] Figure 24 gives a table of these figures in more detail, broken up by field.

Rossiter studied only a sample of 500 men selected at random from the 1921 edition of American Men of Science, but the 17 male astronomers in this sample can provide some comparison with the women. There is no reason to have confidence in these results, but they indicate possible trends. Twelve of the men astronomers (71 percent) were employed in academic institutions, as compared with 95 percent of the women astronomers. Seven of the men held Ph.D.'s (41 percent) as compared with 24 percent of the women. Of all the male scientists in her sample, 63 percent held jobs in academia and 47 percent had Ph.D.'s (Ph.D.'s are correlated more strongly with age than with sex).[7]

There are many problems with the data source for these figures. The fact that only one woman astronomer not connected with an academic institution is listed is clear evidence that American Men of Science is not very complete.

	No.	% of total	Ph.D.s	% Ph.D.s	Mar-ried	% Mar-ried	Academia		% acad.
							Prof.s	other	
Zoology	92	18.3	59	64.1	26	28.3	50	9	64.1
Botany	91	18.1	49	53.8	17	18.7	50	6	61.5
Psychology	69	13.7	62	89.9	18	26.1	40	4	63.8
Medical Sci.	63	12.5	24	38.1	13	20.6	26	9	55.6
Mathematics	46	9.1	36	78.3	6	13.0	40	0	87.0
Chemistry	42	8.3	34	81.0	6	14.3	28	0	66.7
Geology	25	5.0	16	64.0	3	12.0	14	7	84.0
Home Ec.	23	4.6	17	73.9	3	13.0	18	0	78.3
Physics	23	4.6	15	65.2	0	0.0	18	0	78.3
Astronomy	21	4.2	5	23.8	2	9.5	10	10	95.2
Anthropology	9	1.8	2	22.2	4	44.4	1	4	55.6
Total (avg.)	504		319	63.3	98	19.4	344		68.3

Fig. 24. Fields, Doctorates, Marital Status, and Occupation of Women Scientists in Various Fields (Rossiter, "Women Scientists," p. 315).

There were a number of women at Mount Wilson and the Naval Observatory doing more significant scientific research than the professors at the women's colleges, most of whom are listed. Rossiter's paper is just about the only statistical study of women scientists in the period in America that has been done, and the scope of this thesis did not allow the detailed study that would have been required to get better information. American Men of Science is not a very dependable source, but it is convenient, and a further study could give important (though limited) information of the differences between the careers of men and women scientists. It contains information which Rossiter did not utilize on age, length of stay in each job, mobility, membership in societies, and patterns of development of careers. A more rigorous study of the position of women scientists would probably have to be based on numbers of papers published in scientific journals, but this would involve difficulties in evaluating the prestige of various journals and it might be extremely difficult to find biographical material on many of the women.

Women Astronomers I Have Found

The information on the careers of the 164 women working in astronomy who have turned up during the course of my study can give a more detailed picture. The problem is that these women were not selected by any coherent criteria, and my information is often very incomplete. They

are all women who held jobs doing astronomical work or were recognized for significant work done as volunteers or amateurs. There is no doubt an overrepresentation of graduates of women's colleges and women associated with Harvard and Dudley Observatories, because of the nature of my sources. The full list of women is given in appendix C. The women listed include every woman on the staff list of Harvard and Dudley Observatories, graduates of women's colleges who held astronomical jobs after graduation, and women mentioned in astronomical journals or popular articles on women in astronomy written at the time. Figure 25 gives the number of listed women employed at each observatory. Of the women listed, 53 received B.A.'s from women's colleges, and these are the group which will be examined most closely, because alumnae biographical registers give information on their careers. First, though, it is necessary to look briefly at who the other women were.

Information is scanty on the women who are not identifiable as graduates of women's college, but they can be divided into four distinct groups. Twelve are graduates of other colleges: two each from Carleton College and Boston University and one each from the University of Michigan, Columbia, University of Chicago, Ohio Wesleyan, Swarthmore, University of Denver, Guilford College in South Carolina, and Girton College in England. Four are women who gained reputations as astronomers by assisting their husbands. Ten of the remaining women can be identified as not having a

Allegheny	2
Carleton	3
Dearborn	1
Dudley	29
Harvard	45
Lick	4
Mt. Holyoke	7
Mt. Wilson	12
Naval Obs.	6
Smith	10
Swarthmore	2
Vassar	13
Washburn	1
Wellesley	2
Yale	4
Yerkes	12

Fig. 25. Number of Women Whose Careers are Known Who Worked at Each of the Major Observatories.

college education; the rest are women who worked at observatories but for whom there is no information on their college educations, if any. Some of these are probably women who were educated at the western and midwestern coeducational colleges and universities which were being established at about this time. A study of the archival records of the large western and midwestern observatories, such as Yerkes and Mount Wilson, is needed to find out more about these women. A fairly large proportion of the women working in the large observatories probably had no college education; this has been shown to be true at Harvard at least. The women listed who worked at big observatories away from the east coast were discovered mostly because they wrote papers in the astronomical journals, and therefore were probably the best educated of the women at their observatories. Because the staff lists for the Harvard and Dudley Observatories were available, a disproportionate number of women who worked there are listed.

Fifty-three women astronomers were found in the course of this study who had graduated from women's colleges. Of these, 27 went to Vassar, 15 went to Smith, seven went to Mount Holyoke, three went to Radcliffe, and one went to Wellesley. Thirteen of these women ended up in jobs having nothing to do with astronomy and four ended up in related university jobs, such as professor of mathematics. Six were married within five years of graduation, six more

within ten years, and a total of 16 married eventually. There is no evidence that any continued work after marriage. Twenty-three of the college graduates taught high school at some time in their careers. Nineteen earned masters degrees and nine earned Ph.D.'s.

Figures 26 and 27 give place of work and institution where higher degrees were earned for the women's college graduates. The table of places of work includes all jobs held, so some people are counted more than once.

Papers by Women in the Astronomical Journals

I searched the three major American astronomical journals, the Astrophysical Journal, the Astronomical Journal, and Popular Astronomy, for papers by women between 1875 and 1920. Women were identified by their first names, or by the use of Miss or Mrs. Doubtful first names and initials were assumed to be men unless known to be women from other sources. Names which were given with first initials only do not appear to have been a substantial source of error because the first name was given in full for all but one or two of the known women. Co-authoring of papers by men and women was not a common practice, but when such papers occurred they were counted as papers by men. Papers published in parts in different issues were counted as if each part was a separate paper. Only major papers were counted, not minor notes or regular departments.

	Vassar	Smith	Rad-cliffe	Mt.Ho-lyoke	Well-esley
Women's college	10	7	1	5	0
Allegheny	1	0	0	1	0
Carleton	0	1	0	0	0
Columbia	3	0	0	0	0
Harvard	3	1	3	0	1
Lick	2	0	0	1	0
Mt. Wilson	5	1	0	3	0
Naval Obs.	1	1	0	2	0
Yale	1	0	0	0	0
Yerkes	5	3	0	1	0

Fig. 26. Number of Graduates of Various Women's Colleges Who Worked at Each Observatory.

	Vassar	Smith	Mt.Holyoke
Brown	1	0	0
Chicago	2	1	1
Columbia	3	1	0
Mt. Holyoke	0	0	1
Michigan	0	1	0
Radcliffe	2	2	0
Smith	1	3	0
Univ. Calif.	1	1	0
U. Southern Cal.	0	0	1
Vassar	5	0	0
Yale	1	1	0

Fig. 27. Universities From Which Graduates of Women's Colleges Received Higher Degrees.

Figures 28-33 give number of papers by women and percentage of papers by women in each volume or year of the three journals. The most prolific authors were Mary Whitney of Vassar with 48 papers and Mary Byrd of Smith with 28. Care should be taken in interpreting any trends seen in these figures; it takes only a few papers to change the percentage of papers by women considerably. Many of the variations are probably caused by changes in the number of papers submitted by women, which is affected by such outside factors as the teaching load at a particular college in a particular year and the number of comets which appear in a given year.

Endnotes to Appendix A

[1]J. McKeen Cattell, American Men of Science: A Biographical Directory, 2nd edition (New York: The Science Press, 1910).

[2]Margaret W. Rossiter, "Women Scientists in America Before 1920," American Scientist 62 (1974): 312.

[3]Ibid., pp. 312-23.

[4]Ibid., p. 321.

[5]Ibid., p. 315.

[6]Ibid.

[7]Ibid., p. 313.

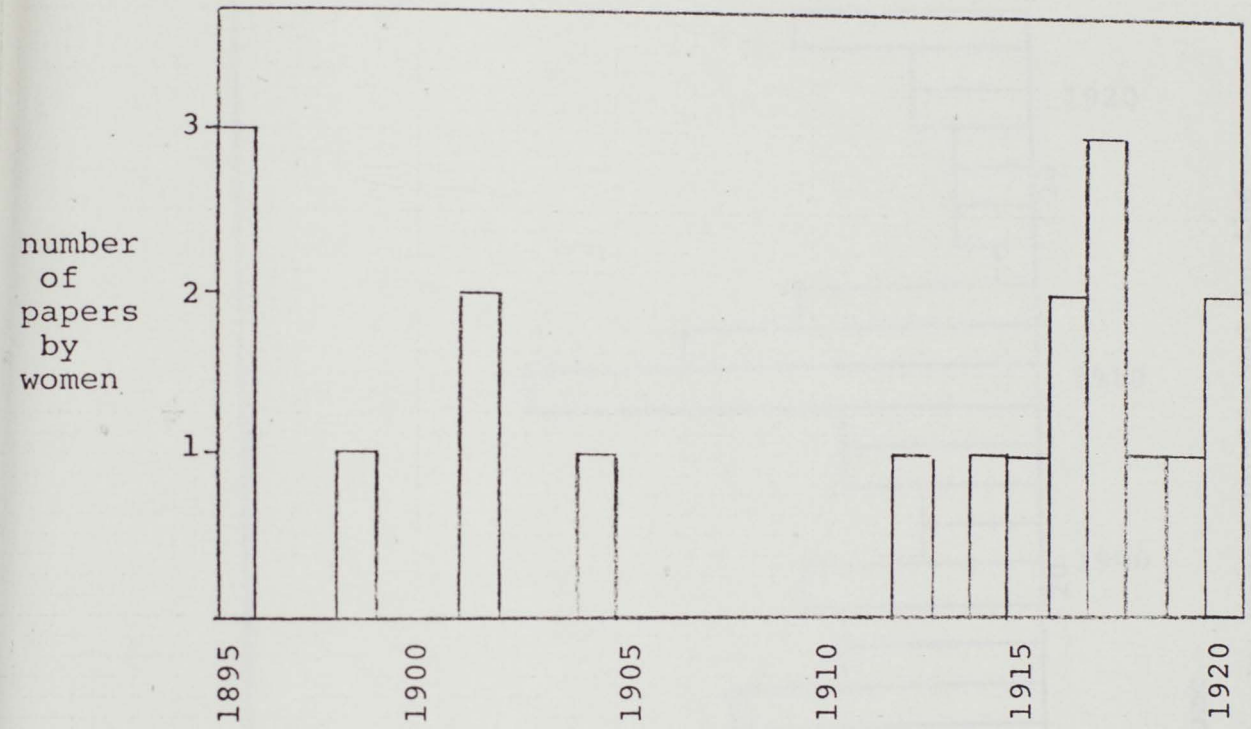

Fig. 28. Number of Papers by Women Published in the Astrophysical Journal between 1895 and 1920.

Fig. 29. Percentage of Papers Published in the Astrophysical Journal that were written by women, between 1895 and 1920.

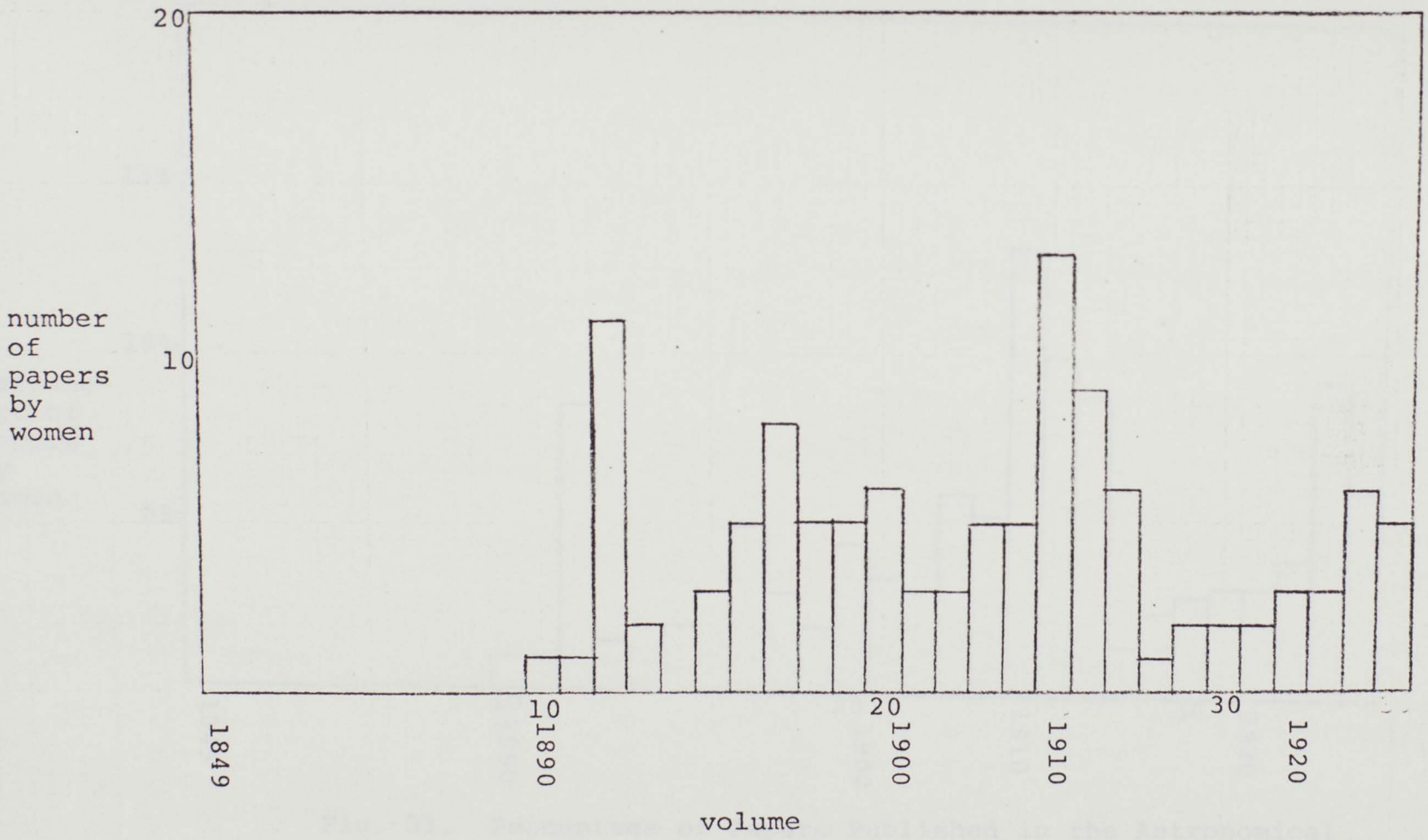

Fig. 30. Number of Papers By Women Published in the Astronomical Journal Between 1849 and 1924.

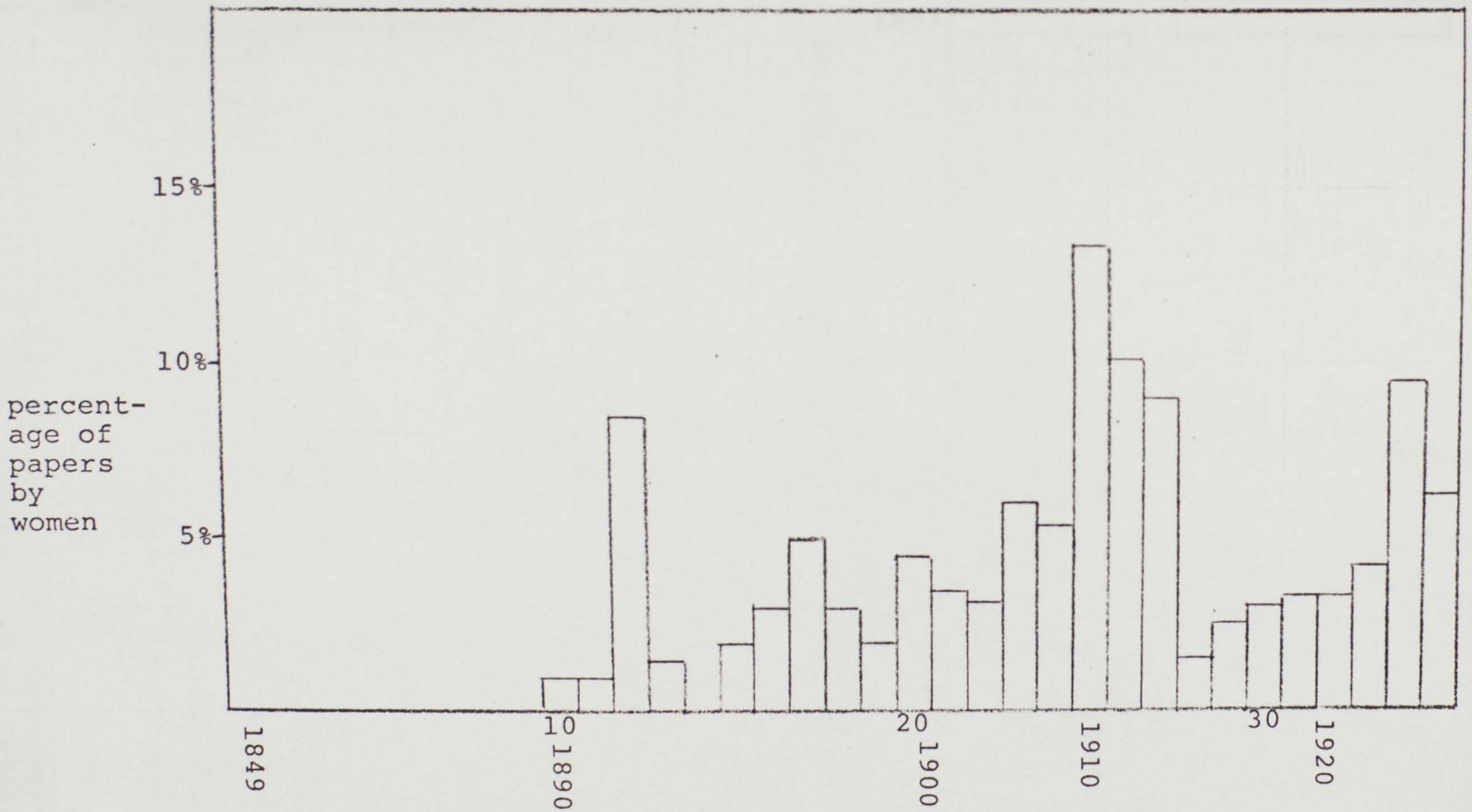

Fig. 31. Percentage of Papers Published in the Astronomical Journal that were written by women, 1849-1924.

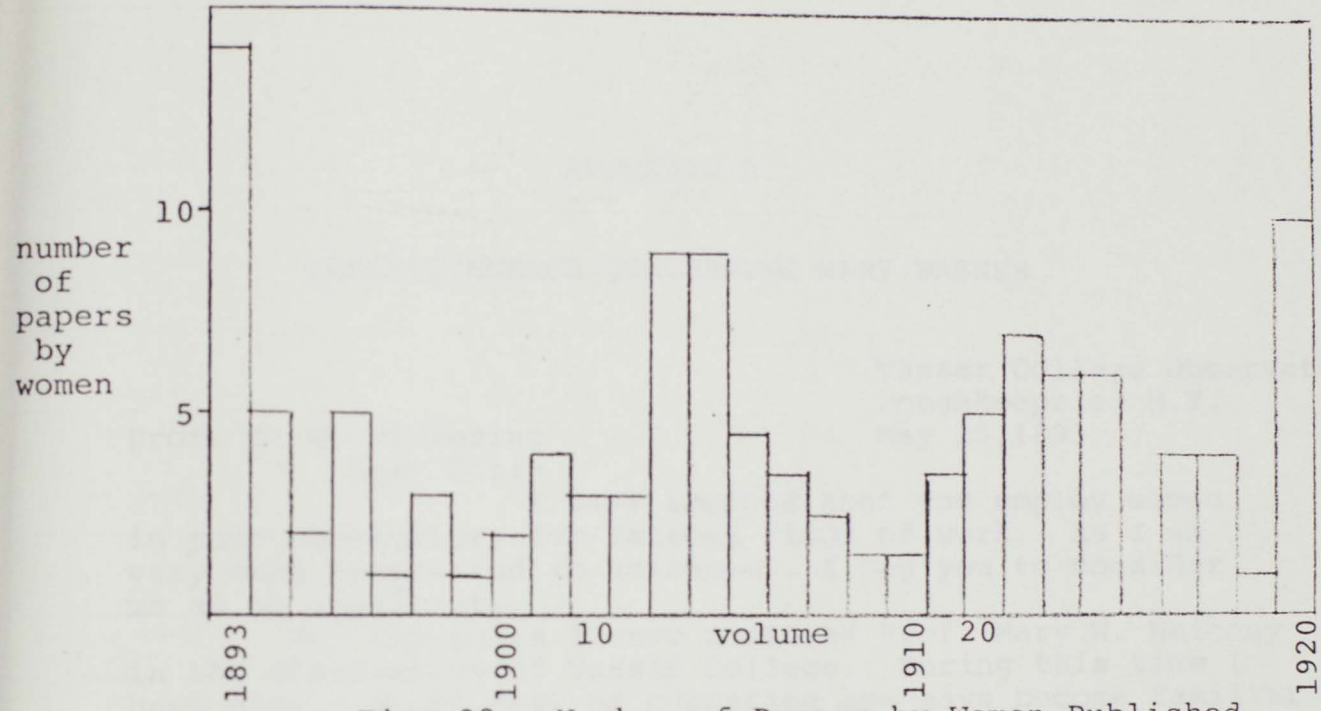

Fig. 32. Number of Papers by Women Published in Popular Astronomy between 1893 and 1920.

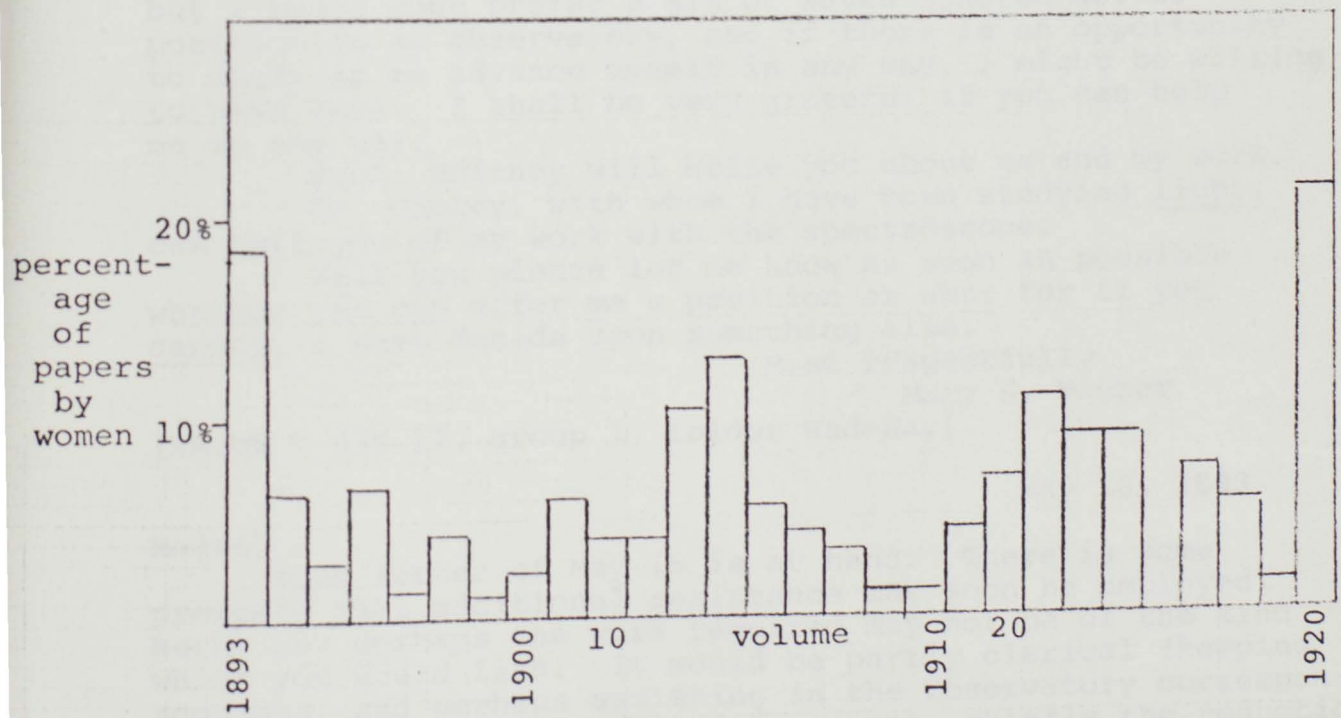

Fig. 33. Percentage of Papers Published in Popular Astronomy that were written by women, 1893-1920.

APPENDIX B

CORRESPONDENCE CONCERNING MARY WAGNER

Vassar College Observatory
Poughkeepsie, N.Y.
May 15,1893

Prof. E. C. Pickering

Dear Sir:-

I have learned that you employ women in your observatory for various kinds of work. As I am very much interested in astronomy, I beg you to consider me as an applicant.

For two years I have assisted Prof. Mary W. Whitney in the Observatory of Vassar College. During this time I have done a great deal of computing and have become familiar with most of the instruments, expecially the spectroscope, which I have used in the laboratory as well as the observatory.

Before entering college, I taught five years and received a fair salary. I have no doubt that I can get nine or ten hundred dollars a year in some high school, but I would much prefer a six or seven hundred dollar position in an observatory, and if there is an opportunity to study or to advance myself in any way, I might be willing to take less. I shall be very grateful if you can help me in any way.

Prof. Whitney will write you about me and my work.

Dr. Cooley, with whom I have been studying light, can tell you of my work with the spectroscope.

Will you please let me know as soon as possible whether you can offer me a position or not; for if you cannot, I must decide upon something else.

Most respectfully
Mary S. Wagner

[HA:UA V 630.17, group 1, folder Wad-Way]

May 18, 1893

Madam,

Your letter of May 15 is at hand. There is some prospect that additional assistance may soon be employed here, but perhaps the work required may not be of the kind which you would like. It would be partly clerical (keeping accounts, and perhaps assisting in the Observatory correspondence) and partly computing (at present, chiefly the reduction of the meridian circle observations). Seven hours' work a

day would be expected, with one month's vacation. The salary would be five hundred dollars a year at first, with a prospect of some increase if justified by the character of the work done.

If you desire such a situation, I shall be glad to hear from you again upon the subject. If you write within the next ten days, your letter may be addressed to Professor Arthur Searle of this Observatory, as I may be absent on a visit to Chicago. Professor Searle would be able to give you any further details with regard to the character of the work which you may wish to know.

Very truly yours

Edward C. Pickering

Miss Mary S. Wagner
Vassar College Observatory
Poughkeepsie, N.Y.

[HA: UA V 630.14, letter book All p. 635]

Vassar College Observatory
May 22, 1893

Prof. Arthur Searle

Dear Sir:

I received a letter from Professor Pickering last week saying that you might soon need another assistant.

I should like to spend a year, at least, in the Harvard Observatory and am perfectly willing to compute, to write letters or to do anything that may be required of me. I am more fond of practical work and have a good eye for seeing; I have used the telescope, microscope, and spectroscope a great deal. In case you wish me to do other work than computing I may be able to do it. I am satisfied however to give my whole time to computing if you so desire.

If you care to offer me a postion when will the work begin? I expected to spend two months in the west this summer but can change my plans if necessary. Please let me hear from you as soon as convenient for I have other work under consideration.

Very respectfully,

Mary S. Wagner

[HA: UA V 630.17, group 1, folder Wad-Way]

May 23, 1893

Madam,

Your letter of May 22 is at hand. I presume that your application will be cordially supported by Professor Whitney, who may have written to Professor Pickering already. In that case, I have no doubt that Professor Pickering will be glad to have the advantage of your assistance here upon the terms stated in his letter of May 18. I fear that there will be little opportunity for you here in the way of telescopic work. If you can conveniently do so, I should recommend you to visit this Observatory in order to obtain a better knowledge of the situation than correspondence can afford. As regards the time of beginning

work, that might probably be arranged to suit your convenience, although an early date would be desirable.

Very truly yours
Arthur Searle

[HA: UA V 630.14, letter book All, p. 646]

May 26, 1893

Prof. Searle
Dear Sir,

Your letter was received today. I thank you very much for the offer and think I shall accept it.

If you are willing, however, I should like to consider the matter a little more fully and to consult Miss Whitney who is now absent. I expect to hear from her in a few days and will try to give you a decisive answer by June 1st.

I have another postion in view, which will pay me much better. It hurts my pride to work for five hundred dollars, but I have a great desire to see your observatory and to work there a year must surely be instructive to me.

I do not care to enter a position before the first of August or September. If you desire me to begin sooner I may be able to arrange it. I am very tired now and perhaps can do better work for you after I have had a complete rest.

Please pardon my indecision and if it is necessary for you to know positively whether I will accept the position or not, let me know and I will wire you a reply.

Very respectfully
Mary S. Wagner

[HA: UA V 630.17, group 1, folder Wad-Way]

[further letters concerning when she would start work omitted]

114 6th St. S.E.
Minneapolis, Minn.
Dec. 11, 1893

Dear Professor Searle,

I am sorry that I did not see you before taking my sudden departure, but it is not too late, I trust, to thank you for your kindness and especially for the suggestions you made in regard to future work. I am also grateful for all information you gave in regard to Astronomical observations and etc.

It seems to me that I ought to beg your pardon for complaining to you so often about the work. I hope your new assistant, if you have one, may find joy in cataloguing stars and that she may have no other ambition than to do that well.

Enclosed is a receipt for the money you so kindly loaned me. I believe there was more than sixty-seven cents but I do not know. I took what Prof. Pickering gave me

and then flew.

Do you think they will pay me for the three days of December that I worked? There are twenty-five working days in this month, which will make the amount due me equal to five dollars. There is also a dollar owing me for Sept. I worked 10 days out of twenty six and should have received sixteen dollars instead of fifteen. It is true that I am a few hours behind in my work but as I am not entitled to any of the vacation money perhaps they will be kind enough to pay me for full time. If you think it worth while I will send in a bill or will you have one made out for me?

I am glad to say that my mother improves tho' slowly. She will need my constant care for a number of weeks. I have no doubt that I can get a good position in the public schools of this city in a month or two.

Very sincerely

Mary S. Wagner

[HA: UA V 630.17, group 1, folder Wad-Way]

December 19, 1893

Dear Prof. Searle,-

I have a friend here who says she will help me to pay expenses in Cambridge if you wish me to return.

My mother is out of danger and I think I can leave her in a few weeks.

The Superintendent of schools here says he will give me a position if I desire to remain in Minneapolis and will pay me at least seven hundred dollars a year, that is seventy dollars every four weeks.

The impression has been made, however, that I was sent home, and for that reason I would like to finish the year at the Harvard Observatory.

If I can use the telescope evenings and work four hours a day on the catalogues, I will be satisfied. I should like to have an opportunity of showing you and Prof. Pickering that I can do some good work. If the burden of poverty is not so heavy, I shall be happier.

The seven hours a day with no opportunity of going to Boston to buy a new bonnet or a pair of shoes was simply unbearable. A woman must do a little "shopping" in order to live, you know.

Do you think Prof. Pickering would be willing to employ me at the rate of thirty cents an hour. I shall not be suprised if he refuses to hear of my returning. My reputation is at stake, however, and that means a great deal to me, for it is all that I have.

If Mrs. Eddy cannot give up her evenings to observing, I think Miss Maury would be very glad to work with me.

Very truly yours,

Mary S. Wagner

P.S. If you think Prof. Pickering would object to my returning please say nothing to him about it.
[HA: UA V 630.17, group 1, folder Wad-Way]

Dec. 20, 1893

Dear Prof. Searle,

My trunks arrived yesterday and I found in one of them a Newcomb's Astronomy which I suppose belongs to the Observatory altho' there was no name in it. I send it by this mail to you.

I feel quite sure that Prof. Pickering will not care to have me return. Perhaps you will be kind enough to write to Chas. M. Jordon, Supt. of the Minneapolis Schools, and tell him that I was not sent home or something equivalent. If you will do that I may be able to secure a thousand dollar high school position. If you can conscientiously say anything in my favor I shall be extremely grateful.

Very Sincerely,
Mary S. Wagner

[HA: UA V 630.17, group 1, folder Wad-Way]

114 6th St. S.E.
Minneapolis, Minn.
Feb. 14, '94

Prof. Searle,
Dear Sir,-

If any letters directed to me are left at the Observatory, will you be kind enough to forward them to the above address.

I am sorry to say that there were no vacancies in the high-schools of this city or of St. Paul and as I know nothing of kindergarten-work I am left without a position.

In the evenings and on Saturdays I give private instruction in Astronomy and Biology to some of the city teachers at the rate of fifty cents an hour. Living at home as I do, I am much richer than I could hope to be in Cambridge.

Next week I expect to begin a course in Zoology at the University of Minnesota. So you see, I have the longed-for opportunity to study.

It breaks my heart though when I think of the wooden post that I watched with so much interest from my prison window. I should like to know whether the telescope has been mounted or not. If I had not been so very poor, I would have been delighted with the prospect for I like to observe and I have a good eye, but Astronomy must be left in the hands of the wealthy, while I turn my attentions to something that will give me a living.

Astronomy will receive all due attention; I know from my experience at Harvard that no star or comet will escape their everlasting vigilance.

I have spent about five years studying things celestial. I shall now devote myself to the terrestrial and see if I cannot do something worthy in that line.

I hope you are well and cheerful as usual.

Most respectfully yours,
Mary S. Wagner

[HA: UA V 630.17, group 1, folder Wad-Way]

Vassar College
Feb. 29, 1896

Professor Pickering,
Dear Sir,

I would like to enquire if next fall there will be any opening in your Observatory for an intelligent young woman, interested in Astronomy. Miss Macallester will be graduated at Vassar next June and she would like very much to find some work to do of an astronomical character. She is a young woman of good ability and has been a conscientious and enthusiastic pupil. She is now taking the introductory course in Astrophysics which we offer.

I hesitate somewhat to present a Vassar student to your attention knowing that Miss Wagner must have been in many ways unsuitable for your work, and I fear she gave you some annoyance.

Perhaps, however, you may recall that she made application herself. I doubted at the time her physical fitness for the work, but after she had made the application I hesitated to injure her prospects by expressing this doubt. Miss Macallester is a well and cheerful young woman and will not trouble her employer with nervous instability.

Yours truly,
Mary W. Whitney

[HA: UA V 630.17, group 1, folder Wha-Why]

March 3, 1896

Madam,

Your letter of Feb. 29 is at hand. I wish I could offer Miss Macallister a position here next fall, but no funds are available for increasing the number of computers employed here, and there is no present prospect of any vacancy to be filled. If circumstances should change, I shall remember Miss Macallister's application, and your recommendation.

Miss Wagner's work was very satisfactory to Professor Searle, to whose department it was mainly confined, but she found the monotony of ordinary computing

too much for her, although care had been taken before she came to explain to her that there was no prospect of pecuniary returns for work of a more interesting character.

Very truly yours
Edward C. Pickering

Professor M. W. Whitney
Vassar College
Poughkeepsie, N.Y.

[HA: UA V 630.14, letter book A13, p. 242]

APPENDIX C

LIST OF WOMEN

This list is intended for the use of others who wish to study women in astronomy. It therefore includes the name of every woman whom I know to have been active in astronomy between 1875 and 1920. The information given, when known, is dates of birth and death, education, jobs held, and husband's name if married. For women who are known only by papers they published, the journals and volumes in which the papers were published are given. The following abbreviations are used to indicate sources (see bibliography for further details):

(DO) Benjamin Boss, History of the Dudley Observatory 1852-1956

(HCO) Solon I. Bailey, History and Work of Harvard Observatory 1839-1927

(K) Dorothea Klumpke, "La Femme Dans L'Astronomie"

(M) Anne P. McKenney, "What Women Have Done for Astronomy in the United States"

(NAW) Notable American Women

(WC) The Alumnae Biographical Register of the women's college from which the person received her B.A. degree

AJ Astronomical Journal

ApJ Astrophysical Journal

PA Popular Astronomy

Unless otherwise specified 'taught' is used to mean teaching below the college level.

Allen, Charlotte S.
Worked at the Dudley Observatory 1910-11. (DO)

Allen, Frances E.
B.A. Vassar 1919. Worked as a computer at Yerkes summer 1919.

Applegate, Mary
Worked at Harvard 1918-20. Married Beach. (HCO)

Barber, Harriet Sophia (? -1933)
B.A. Mt. Holyoke 1898. Worked as an assistant at Mt. Holyoke 1902-3. Teacher 1899-1902, 1905-6, 1908-9. Secretary 1909-11. Married Lester H. Humphrey 1912. (WC)

Bardwell, Elizabeth Miller (1831-1899)
Taught 1850-64. Graduated from Mt. Holyoke Female Seminary 1866. Professor of astronomy and director of the observatory at Mt. Holyoke 1866-99.

Barney, Ida
Ph.D. Worked at Yale on catalogues at least 1924-1936. AJ:35.

Benedict, Marguerite S.
Worked at the Dudley Observatory 1910-14. (DO)

Bigelow, Harriet Williams (1870-1934)
A.B. Smith 1893. Ph.D. Univ. of Michigan 1904. Teacher 1894-96. Assistant at Smith 1896-1901. Instructor at Smith 1904-6. Associate professor at Smith 1906-11. Professor at Smith 1911-34. Worked at Yerkes for several months.(WC)

Bingham, Mary E.
Worked at the Dudley Observatory 1914-18. (DO)

Block, Dorothy W.
Worked at Yerkes 1919-? Worked at Harvard 1917-? Married John Paraskevopoulos. (HCO)

Bok, Priscilla Fairfield
B.A. Boston University 1917, Ph.D. Univ. of California 1921. Assistant professor at Smith 1922-31. Married Bart Bok and assisted him in his astronomical work.

Bond, Selina Cranch (1831-1920)
Worked at Harvard 1879-1920. (HCO)

Breslin, Sarah E.
Worked at Harvard 1898-1912. (HCO)

Brooks, Grace R.
Worked at Harvard 1906-1920. (HCO)

Buffum, Grace I.
Worked at the Dudley Observatory 1904-1933. (DO)

Burns, Carolyn E. O.
Studied at Radcliffe 1908-09. Worked at Mt. Wilson.

Byrd, Mary Emma (1849-1934)
B.A. Univ. of Michigan 1878. Studied at Harvard Observatory 1882-83. Ph.D. Carleton College 1904. Teacher 1879-82. Director of the Smith College Observatory 1887-1906. Professor of astronomy at Smith 1896-1906.

Campbell, Florence M.
No formal training in astronomy. Worked at Harvard 1925-?

Cannon, Annie Jump (1863-1941)
B.A. Wellesley 1884. Worked at Harvard 1896-1941.

Carpenter, Alta M.
Worked at Harvard 1906-20. (HCO)

Clark, Livia G.
Worked at the Dudley Observatory 1904-1922. (DO)

Cobb, Harriet Redfield
B.A. Smith 1889, M.A. Smith 1891. Studied at Columbia summers 1914,1915. Teacher 1889-90, 1891-95. Professor of mathematics at Smith 1895-1932. (WC)

Cowley, Elizabeth B.
B.A. Vassar 1901, M.A. Vassar 1902, Ph.D. Columbia 1908. Studied at Chicago, Göttingen, Munich. Associate professor of mathematics at Vassar 1902-29. (WC)

Cunningham, Susan J. (1842-1921)
Honorary Sc.D. Swarthmore 1888. Studied at Vassar 1866-67,Harvard summers 1874,76, Princeton summer 1881, Cambridge, England summers 1877,78,79,82,87,91, Williams summers 1883, 84. Professor of mathematics and astronomy at Swarthmore 1872-1906.

Cushman, Florence
Worked at Harvard 1888-? (HCO)

Davis, Alice E. (? -1923)
B.A. Vassar 1900, M.A. Vassar 1901. Taught. (WC)

Davis, Corcita Register Hoffecker
Married Herman Stearns Davis. Assisted her husband in the New Reduction of Piazzi's Star Catalogue.(K)

Davis, Elizabeth Brown
Studied at Johns Hopkins. Was working with E. E. Barnard at Lick in 1891. Worked at the Naval Observatory. Married Davis. (K) (M)

Davis, Helen L. (? -1930)
B.A. Vassar 1899, B.S. Columbia 1910. Worked at Columbia 1899-1908. Head of the department of household art at Univ. of Nebraska 1910-17. Professor at Oregon Agricultural College 1917-30. (WC)

Davis, Helen N.
Worked at Mt. Wilson. Instructor in physics dept. at Vassar. Worked at Yerkes summer 1919.

Dobbin, Emily Elisabeth
B.A. Univ. of Chicago 1904. Worked at Yerkes 1902. ApJ:19.

Doran, Mabel I.
Worked at the Dudley Observatory 1918-20. (DO)

Draper, Mary Anna Palmer (1839-1914)
Married Henry Draper. Assisted her husband. Gave money to Harvard.

Dyer, Mabel
Worked at the Dudley Observatory 1907-17. (DO)

Eaton, Etta M. (? -1915)
B.A. Mount Holyoke 1889. Taught 1889-90, 1893-95. Postmaster, Lancaster, N.Y. 1897-99. Worked at the Naval Observatory 1900-15. (WC)

Eddy, I. W.
Worked at Harvard 1889-1904. (HCO)

Eddy, Mary B.
Worked at the Dudley Observatory 1910-11. (DO)

Winifred Edgerton
B.A. Wellesley 1883, Ph.D. Columbia 1886. Worked at Columbia. Married Merril approx. 1887.

Ensign, Inez A.
B.A. Mt. Holyoke 1911, M.A. Univ. of Southern California 1932. Worked at Mt. Wilson 1911-14. Secretary 1914-18. Statistician for the War Department 1918-19. Computer Astrophysical Observatory (Smithsonian?) Washington D.C. 1919. Secretary 1923-33. (WC)

Everett, Alice
Graduate of Girton, in England. Assistant at Vassar 1898-99.

Farnham, Margaret
Worked at the Dudley Observatory 1914-? (DO)

Farnsworth, Alice Hall
B.A. Mt. Holyoke 1916, M.A. Mt. Holyoke 1917, Ph.D. Univ. of Chicago 1920. Studied at Yerkes 1916-20. Worked at Lick 1930-31. Instructor at University of Chicago 1920-22. Assistant professor at Mount Holyoke 1922-25,1926-28. Associate professor 1928-?. Director of observatory at Mt. Holyoke 1936-? (WC)

Farrar, Nettie A.
Worked at Harvard 1881-1885. (HCO)

Fleming, Williamina Paton Stevens (1857-1911)
High school education only. Worked at Harvard 1881-1911. (NAW)

Fowler, Lillian V.
Worked at the Dudley Observatory 1904-1928. (DO)

Fowler, Mary
B.A. Vassar 1911. Hired by Allegheny but not listed as having worked there. Studied at Simmons 1920-21. Secretary 1922-? (WC)

France, Jennie V.
Was working at Yale in 1922. AJ:34.

Fuller, Alice M.
Worked at the Dudley Observatory 1911-23. (DO)

Fuller, Ernestine W.
M.A. Assistant at Vassar 1913-16.

Furness, Caroline Ellen (1869-1936)
B.A. Vassar 1891, Ph.D. Columbia 1900. Studied at Ohio State 1892-94. Taught 1891-94. Worked at Yerkes summer 1899. Worked in astrophysical lab at Groningen 1908. Assistant at Vassar 1894-98 Professor at Vassar 1899-1936. (WC)

Gale, Florence
Worked at the Dudley Observatory 1913-18. (DO)

Gill, Edith F.
Worked at Harvard 1889-? (HCO)

Gill, Laura Drake (? -1926)
B.A. Simth 1881, M.A. Smith 1885, D.C.L. Univ. of the South 1907. Studied Smith 1881-89, Leipzig 1890-92, Geneva 1892, Sorbonne 1892-93, Cornell 1919-20. Taught 1881-90, 1893-98. Nursing work 1898, 1899-1901. Dean at Barnard 1901-1908. (WC)

Gill, Mabel A.
Worked at Harvard 1892-? (HCO)

Glancy, Anna Estelle
Ph.D. Univ. of California 1913. Fellow at Lick 1908-10. Worked at the National Argentine Observatory, Cordoba, Argentina 1913-?

Guiler, Charlotte Gertrude
B.A. Ohio Welseyan 1925, M.A. Smith. Instructor at Smith 1925-32.

Gushee, Vera Marie
B.A.Smith 1916, M.S. Univ. of Chicago. Studied Chicago 1916-17, Smith 1917-19, Northwestern 1924-25. Worked at Yerkes 1916-17. Worked at the Naval Observatory summer 1918. Demonstrator, assistant, assistant professor at Smith 1917-27. Instructor at Northwestern 1924-25. Instructor at Ohio State 1925. Instructor at Pine Manor, Wellesley 1927-? (WC)

Hall, Angeline Stickney (1830-1892)
Married Asaph Hall. Helped her husband.

Hall, S. H.
Worked at Harvard 1897-1900. Married P. F. Bonesteele. (HCO)

Harpham, F. E.
M.A. Carleton College. Assistant at Smith 1893-96. Worked at Columbia 1896-1910. Taught at the College for Women, Columbia, S.C. 1910-?

Harriman, Maude E.
Worked at Harvard 1900-5. (HCO)

Harwood, Margaret (1885-)
B.A. Radcliffe 1907, M.A. Univ. of California 1916. Worked at Harvard 1907-12. Fellow of Maria Mitchell Association 1912-16, Director of the Maria Mitchell Observatory 1916-57.

Hawes, Marian Alberta
B.A. Radcliffe 1914. Worked at Harvard 1912-18. Assistant professor at Vassar 1920-32. Worked at the Dudley Observatory 1925-? Married William Henry 1935. (HCO) (DO)

Hayes, Helen.
Instructor of mathematics at Wellesley around 1903. Worked at Columbia. (K)

Hazen, Louise Coleman
B.A. Smith 1898. Studied Univ. of Pennsylvania 1900-1, Dartmouth summer 1902, Univ. of Texas 1902-3. Taught 1898-1931. (WC)

Herber, Mary J.
Worked at the Dudley Observatory 1914-18. (DO)

Hill, Laura E.
M.A. Instructor at Vassar 1924-27. Working at Dearborn Observatory in 1922. AJ:34.

Hodgdon, Lillian L.
Worked at Harvard 1889-? (HCO)

Howe, Mary B.
B.A. Vassar 1922, M.A. Radcliffe 1925. Worked at Lick 1922-23. Assistant at Vassar 1923-24. Worked at Harvard 1924-25. Taught 1925-26. Married Robert H. Baker 1926. (WC)

Howe, Mary E.
Worked at Harvard 1907-9. (HCO)

Howell, Janet T.
Working at Mt. Wilson in 1916. ApJ:44.

Hopkins, Mary Murray (? -1921)
B.A. Smith 1899, M.A. Columbia 1911, Ph.D. Columbia 1915. Studied at Yerkes summers 1912, 1913. Taught 1899-1906. Assistant at Smith 1906-8. Instructor at Smith 1908-15. Associate professor at Smith 1915-21. (WC)

Jacoby, Annie Maclear
Worked at Columbia around 1899. Married Harold Jacoby. (K)

James, Mary B.
Worked at the Dudley Observatory 1918-19. (DO)

Jenkins, Louise Freeland
B.A. Mount Holyoke 1911, M.A. Mount Holyoke 1917. Assistant at Mount Holyoke 1911-13. Worked at Allegheny 1913-15. Instructor at Mount Holyoke 1915-20. Missionary 1920-32. (WC)

Jennings, Florence
Worked at the Dudley Observatory 1911-? (DO)

Jennings, Mary C.
Worked at the Dudley Observatory 1907-13. (DO)

Jones, Bertha W.
Worked at the Dudley Observatory 1913-18. (DO)

Joslin, Mary Reed
B.L. Smith 1898. Studied at Radcliffe 1898-99. Tutor at Radclifee 1899-1903. Stenographer 1906-11. Writer. (WC)

Klumpke, Dorothea (1861-1942)
Native of California. Doctor of science degree from the Univ. of Paris, 1893. Worked at the Paris Observatory. Married Isaac Roberts. (M)

Laird, Elizabeth R.
At Bryn Mawr. ApJ:14 (1901).

Lamson, Eleanor A.
Working at the Naval Observatory in 1905. AJ:23.

Lange, Isabelle
Worked at the Dudley Observatory 1910-40. (DO)

Lange, Marie
Worked at the Dudley Observatory 1915-31. (DO)

Lasby, Jennie
M.A. Mt. Holyoke 1906. Working at Mt. Wilson in 1911. Married Tessman. PA:19.

Leavitt, Henrietta Swan (1868-1921)
B.A. Radcliffe 1892. Worked at Harvard 1902-21. (HCO)

Leland, Evelyn
Worked at Harvard 1889-1925. (HCO)

Lewis, Anna Delia
B.A. Carleton College 1889, Ph.D. Carleton 1896. Taught at Carleton College, Albert Lea College, Mt. Holyoke College, and Lake Erie College.

Mace, Hannah F.
B.A. Vassar 1890. Studied Vassar 1892-93, Yale 1893-94. Taught 1890-92. Worked at the Naval Observatory 1894-? (WC)

Mackie, Johanna C. S.
Worked at Harvard 1903-20. (HCO)

MacNeil, Frances
Worked at the Dudley Observatory 1910-33. (DO)

MacNeill, Helen
Worked at the Dudley Observatory 1918-20. (DO)

Magill, Eudora
B.A. Swarthmore. Worked at Columbia. Working at Yerkes in 1912. (M)

Martin, Martha Evans (? -1925)
Wrote popularizations of astronomy.

Masters, Annie E.
Worked at Harvard 1887-1889. (HCO)

Mathews, Genevieve F.
Worked at Harvard 1912-1916. (HCO)

Maury, Antonia Gaetana de Paiva Pereira (1866-1952)
B.A. Vassar 1887. Worked at Harvard 1889-97, 1917-35. Teacher 1891-94, 1909-10. (NAW) (HCO)

McElroy, Alice
Worked at the Dudley Observatory 1910-11. (DO)

McKay, Amy J.
Worked at Harvard 1891-1906. (HCO)

Mead, Gertrude M. (? -1931)
B.A. Vassar 1870. Studied Vassar 1870-71, Columbia 1876-77, Col. de France and Sorbonne 1882-83. Taught 1874-76. Married Edwin A. Abbey 1890. (WC)

Merriman, Mabel L.
B.A. Smith 1894, M.A. Radcliffe 1901. Studied at Chicago 1896-97. Teacher 1895-96. Assistant at Lowe Observatory, Echo Mountain, California 1895-6. Teacher 1897-98, 1904-7. Instructor, assistant professor of biology at Hunter College 1907-? (WC)

Michaelis, Marion F.
Worked at Harvard 1900-1906. (HCO)

Mitchell, Maria (1818-1889)
Worked for the Coast Survey 1849-68. Professor of astronomy at Vassar 1865-88.

Moak, Mary G.
Worked at the Dudley Observatory 1910-13. (DO)

Moulton, Mary Etta
B.A. Carleton College 1894. Missionary work in India.

Morris, Gwendolin
Worked at the Dudley Observatory 1913-? (DO)

Newman, Ruth M.
Worked at the Dudley Observatory 1910-11. (DO)

O'Reilley, Mollie E.
Worked at Harvard 1906-18. Married Sloan. (HCO)

O'Halloran, Rose
Dedicated California amateur. PA:7,10... (1899-1913).

Palmer, Margaretta (? -1924)
B.A. Vassar 1887, Ph.D. Yale 1894. Taught Latin at Vassar 1887-89. Worked at Yale 1894-1924. (WC)

Parsons, Harriet McW.
B.A. Vassar 1915, M.S. Univ. of Chicago 1916, Ph.D. Univ. of Chicago 1921. Instructor at Smith 1916-19. Worked at Yerkes 1919. Assistant professor at Smith 1921-23. Married Henry T. Hall 1923. (WC)

Peirce, Katharine U. (? -1929)
B.A. Vassar 1889, M.A. Brown 1911. Worked at Columbia 1896-97. Head of the department of science at Milwaukee College 1889-93. Teacher 1893-96, 1898-1929. (WC)

Peters, Amy Flora
B.A. Mt. Holyoke 1902. Studied Mt. Holyoke 1902-3. Assistant at Mt. Holyoke 1903-4. Teacher 1902-3, 1904-6. Married Alfred E. Nickerson 1906. (WC)

Proctor, Mary (1862- ?)
Lectured on astronomy and briefly edited a department of Popular Astronomy. PA:5.

Quincy, Eliza
Amateur observer associated with Harvard around 1850.

Raymond, Susan
B.A. Smith 1913, M.A. Smith 1919. Associate fellow Maria Mitchell Association 1915-16. Maria Mitchell fellow at Harvard 1916-17. Demonstrator at Smith 1913-15. Instructor at Smith 1917-22. Taught 1913-15. Married Harold S. King 1922. (WC)

Renner, Martha
Studied at Vassar. Worked at Mt. Wilson 1911-12. Married Ralph A. Sandy 1919. (WC)

Richmond, Myrtle Leila
B.A. Smith 1907, M.A. Denver 1908. Studied at Denver 1907-12, Carleton 1912-13. Taught mathematics at the Univ. of Denver 1907-12, Carleton 1912-13. Worked at Mt. Wilson 1913-? (WC)

Ritchie, Mary
B.A. Vassar 1914. Studied Univ. of Chicago 1932. Taught 1915-18. Assistant at Vassar 1926-27. Statistics clerk in War Dept. 1918-19. Worked at Mt. Wilson 1919-20. Social work 1932-37. (WC)

Rogers, R. T.
Worked at Harvard 1875-1898. (HCO)

Rugg, Jennie T.
Worked at Harvard 1887-89. (HCO)

Saunders, R. G.
Worked at Harvard 1875-88. (HCO)

Schindler, Theresa Elizabeth (? -1934)
B.A. Mt. Holyoke 1906. Assistant at Mt. Holyoke 1906-7. Studied Univ. of Chicago summer 1914, Cornell 1918. Taught 1907-? (WC)

Searle, Katharine
B.A. Radcliffe 1901. Studied at Smith 1895-6. Taught 1900-2. Secretary 1902-3. Worked at Harvard 1904-12. Writer. (WC)

Sheldon, Wanda
B.A. Vassar 1911. Hired to work at Mt. Wilson. Married Edgar C. Nichols 1913. (WC)

Slocum, Lois Trip (? -1951)
B.A. Smith 1921, M.A. Univ. of California 1924, Ph.D. Univ. of California 1930. Taught 1921-22. Assistant at Smith 1922-25. Instructor at Wellesley 1925-27. Assistant professor at Wellesley 1930-31. Research assistant Wesleyan 1931-32. Assistant professor at Smith 1934-? (WC)

Smith, Ruth E.
B.A. Vassar 1906. Worked at Mt. Wilson 1906-15. Married Gerhard Bakker 1915. (WC)

Smith, S. E.
Studied at MIT, Michigan. Taught at Mt. Holyoke 1892.

Steele, Hannah B.
Studied at Univ. of Chicago. Assistant at Swarthmore. Worked at Yerkes 1916-?

Stevens, Harriet I.
Worked at Harvard 1891-1910. (HCO)

Stevens, Ida M.
Cambridge High School. Worked at Harvard 1904-9. (HCO)

Stevens, Mabel C.
Worked at Harvard 1888-1906. (HCO)

Storin, Nellie C.
Worked at Harvard 1887-89. (HCO)

Sutton, Psyche R.
B.A. Vassar 1910, M.A. Vassar 1910. Assistant at Vassar 1910-12. Married Harold J. Underwood 1912 (WC)

Tarbox, Mary E.
B.A. Vassar 1896. Studied at Vassar 1896-97. Worked at Columbia 1898-1902. Taught 1902-5. Married LeRoy N. Babbitt 1905. (WC)

Todd, Mabel Loomis (1858-1932)
Married David P. Todd. Wrote a number of books about the sun. (K)

Tompkins, Elizabeth M.
B.A. Vassar 1899, M.A. Columbia 1915. Studied at Vassar 1899-1900. Assistant at Vassar 1903-5. Taught 1901-2, 1905-? (WC)

Traylor, Mary Clark
At the Univ. of Denver in 1902. PA:9.

Updegraff, Alice Lamb
Assistant astronomer at the Washburn Observatory 1885-87. Married Milton Updegraff 1887. Worked at the National Argentine Observatory 1887-90. (M)

Wagner, Mary S.
Studied at Vassar 1891-93. B.S. Univ. of Minnesota 1897. Worked at Harvard 1893. Owner and manager of the Wagner Inn, Poughkeepsie, N.Y. 1902-22. (WC)

Walker, Arville D.
Worked at Harvard 1906-? (HCO)

Walker, Emma E.
Worked at Harvard 1912-18. (HCO)

Ware, Louise
B.A. Vassar 1900. Taught 1901-3. Worked at Yerkes 1903-6. Worked at Mt. Wilson 1906-? (WC)

Waterbury, Ruth C.
Worked at Harvard 1907-10. (HCO)

Waterman, Phoebe E.
B.A. Vassar 1904, M.A. Vassar 1906, Ph.D. Univ. of California 1913. Assistant at Vassar 1908. Worked at Mt. Wilson 1909-11. Vassar College fellow at Lick Observatory 1912-13. Appointed assistant at the Argentine National Observatory 1913. Married Otto Haas 1914.

Watson, Ida I.
Studied at Vassar. PA: 10 (1902).

Wells, Louisa D.
Worked at Harvard 1887-? (HCO)

Wentworth, Gertrude F.
B.A. Boston University. AJ:11 (1891-92).

White, Jessamine M.
B.A. Vassar 1912. Assistant at Vassar 1912-13. Married George S. Hawley 1913. (WC)

Whiteside, Ida
B.A. Vassar 1904, M.A. Vassar 1906. Studied at Harvard 1907-9. Assistant at Wellesley 1907-8. Taught and did missionary work in Egypt 1909-? (WC)

Whiting, Sarah Frances (1847-1927)
Professor of physics at Wellesley 1878-
(NAW)

Whitney, Mary Watson (1847-1921)
B.A. Vassar 1868. Professor of astronomy at Vassar 1888-1910.

Whyte, Marion C.
Worked at Harvard 1911-13. (HCO)

Wickham, Evelyn W.
B.A. Vassar 1916, M.S. Univ. of Chicago 1917. Computer at Yerkes 1916-19. Worked in research department of American Telephone and Telegraph. (WC)

Willard, Charlotte Richards (? -1930)
B.A. Smith 1883. Taught 1883-1887. Assistant at Carleton College 1887-95. Co-editor of Popular Astronomy 1893-95. Taught 1895-1930. (WC)

Wilson, Jane B.
Worked at Harvard 1912-13. (HCO)

Winlock, Anna (1857-1904)
Cambridge High School. Worked at Harvard 1875-1903. (HCO)

Winlock, Louisa
Worked at Harvard 1886-1915. (HCO)

Wolffe, E. Gertrude
Worked at Harvard 1893-99. (HCO)

Woods, Ida E.
Worked at Harvard 1893-? (HCO)

Young, Anne Sewell (? -1961)
B.A. Carleton College 1892, Ph.D. Columbia 1906. Taught 1892-95, 1898. Worked some summers at Yerkes. Professor of Astronomy at Mt. Holyoke 1899-1936.

Zimmer, Meade L.
Worked at the Dudley Observatory 1906-13 (DO).

BIBLIOGRAPHY

Contents

Archival Material

Harvard

The largest part of the time spent on research for this thesis was spent reading archival material at Harvard. The official correspondence of the Harvard College Observatory for the period of Edward C. Pickering's directorship is in the Harvard University Archives in Pusey Library, Cambridge, Mass., under the call numbers UA V 630.14 to UA V 630.17.10. The outgoing correspondence is in the form of letter books, bound books of about 600 pages of copies of handwritten correspondence. The main group of outgoing correspondence is in 36 books in five series, A1 to A19, B1 to B7, C2, D1 to D6, and E1 to E4, under call numbers UA V 630.14 to UA V 630.14.5. Further outgoing correspondence is in 25 more letter books under the call numbers UA V 630.15, UA V 630.15.3, and UA V 630.16. References to the letter books give the call number, the series and number of the letter book, and the page number.

The incoming correspondence is separated into two files, which are separated into groups. File I, which is indicated by its call number, UA V 630.17, is separated into three individually alphabetized groups. Group 1 is dated 1875 to 1899 (incoming) and consists of 14 boxes. Group 2 is dated 1899 to 1902 (incoming) in the catalogue of the archives but is labeled 1876 to 1902 on the boxes (and indeed contains letters dated before 1899); it contains nine boxes.

Group 3 is in 11 boxes and is dated 1903-1920 (incoming and outgoing). File 2, which has the call number UA V 630.17.5, contains correspondence filed in folders for individual correspondents rather than for alphabetical divisions, but this does not appear to reflect any major difference between the types of letter in the two files. File 2 is divided into two groups, 15 boxes for 1875 to 1910 and 37 boxes for 1911 to 1921. Material in these files is referred to by call number, group, and folder; this is sufficient information because the call number indicates which file the letter is in and the boxes are labelled to show which folders they contain (since all files are organized alphabetically). In addition to these files there are four boxes of letters from eminent American astronomers under the call number UA V 630.17.7 and one box of letters from eminent foreign astronomers under the call number UA V 630.17.8.

In addition to the official observatory correspondence I used two other relevant collections in the Harvard Archives. Two boxes of Edward C. Pickering's private letters are under call number HUG 1609.4. Some of Williamina Fleming's correspondence and a scrapbook of notices on her death are preserved under call number HUG 1396.

The vast majority of this material has nothing to do with the position of women at Harvard, but there is no way of separating out the relevant material except by examination. Letter books A1 to A19 and Files 1 and 2 were thoroughly studied, and most of the rest of the material was

at least looked over for familiar names. In dealing with the women at Harvard this material is limited by the fact that when they were at the Observatory there was no need to write letters, but there is still much valuable information about the position of women at Harvard and also correspondences with women at the women's colleges. It is mostly in the form of small clues, but the assembly of enough small clues can give a reasonably coherent picture.

Radcliffe

The Radcliffe Archives in the Schlesinger Library, Cambridge, Mass., contain less relevant material. Under the call number R75-23 is a lecture book containing notes by Professor Searle for the course he taught at Radcliffe, the manuscript of a brief but interesting autobiography by Searle, and course materials. A few original letters about the teaching of astronomy at Radcliffe are in the Radcliffe College records in Record Group I, series 1, volume 1. This last is closed material, and I am grateful to President Matina Horner for permission to examine it. The catalogue of courses and annual reports of the Society for the Collegiate Instruction of Women, as Radcliffe College was originally called, are found under the call number Rad. C. 1. In the Schlesinger Library manuscript collection (which is different from the Radcliffe Archives although located in the same library) under call number B-6 there is a series of letters and papers concerning an exhibit on women in

science prepared by Radcliffe for the Harvard tercentennial in 1936, but it contains only reprints of published papers and letters replying to requests for papers. The Radcliffe material yielded an interesting picture of the early history of astronomy at Radcliffe which is not fully presented in this thesis because of space limitations.

Vassar

The Vassar College Archives, in the Special Collections room of the Vassar College Library, Poughkeepsie, N.Y., provided the basis for the description of the history of astronomy at Vassar. I examined the files containing the department of astronomy correspondence, the file on Mary Whitney, and the handwritten annual reports of the observatory. The department of astronomy correspondence contains a number of very revealing personal letters. Vassar also has an extensive collection of letters and papers of Maria Mitchell, but time prevented the study of these. The Alumnae Biographical Register, 1939 (by Vassar College, Bulletin of Vassar College, Poughkeepsie, N.Y., 1939) was consulted to find the careers of Vassar graduates who had done astronomical work.

Mount Holyoke

The Mount Holyoke College archives in the College History Collection in Williston Memorial Library, South Hadley, Mass., contain similar materials. The file on the observatory

contains a useful manuscript history of astronomy at Mount Holyoke written by Alice H. Farnsworth and a number of letters and clippings. The files on Elizabeth M. Bardwell and Anne S. Young include letters and clippings and some particularly fine photographs. Unfortunately, there are very few personal letters related to astronomy at Mount Holyoke. The 100 Year Biographical Directory of Mount Holyoke College 1837-1937 (by the Alumnae Association of Mount Holyoke College, South Hadley, Mass.: Alumnae Association, 1937) was a source for the careers of graduates.

Smith

Smith College has a particularly good collection of material on the observatory and the department of astronomy in the College Archives, in the Neilson Library, Northampton, Mass. The boxes filed under the department of astronomy contain an interesting assortment of letters about equipment and research. The file for Mary Byrd contains a six page biography done by Richard Serena, some short memoirs of her by her pupils, and some beautiful personal letters. I also studied the handwritten annual reports, which are informal and informative, and the Biographical Register 1871-1935 (by the Alumnae Association of Smith College, Northampton, Mass.: Smith College, 1935).

Wellesley

At Wellesley College I examined the archival material on Sarah Whiting and Annie Cannon in the College Archives in

the Wellesley College Library, Wellesley, Mass. The file on Sarah Whiting contains some interesting letters and a particularly complete and personal history of the physics department from 1878 to 1912 written by Whiting. The Annie J. Cannon file contains letters to Mary E. Lathrop and Edith Tufts which say little about her astronomical work.

Swarthmore

The official archives at Swarthmore College, the Friends Historical Library in the Swarthmore College Library, Swarthmore, Penn., has only a few letters to and from the professor of astronomy in the late nineteenth and early twentieth centuries, Susan J. Cunningham. However, Dr. Sarah Lee Lippincott, present director of the Sproul Observatory of Swarthmore College, kindly let me examine Cunningham's notebooks, which are still kept at the observatory. These consist of 27 notebooks of weather records, observations, and computations, a portfolio containing the typescript of a paper, and 11 notebooks containing notes for popular lectures and a variety of courses on astronomy and mathematics.

Annie J. Cannon Papers Belonging to Margaret Mayall

I am also grateful to Margaret Mayall for permission to study Annie Cannon's diaries and letters. These were examined in Margaret Mayall's home in Cambridge, Mass. The diaries from before 1925, which unfortunately leave a gap from about 1890 to 1910, were examined carefully. The

account of Cannon's activities in the diaries is interesting, but except for the very early years they contain little reflection on her position and what her work meant to her.

Interviews

Helen Sawyer Hogg

Helen Hogg was interviewed on August 16, 1976, in Dunstable, Mass. A graduate of Mount Holyoke College, she received a Ph.D, in astronomy from Harvard in 1931. In the interview, which unfortunately was not taped, she talked about the position of the early graduate students in astronomy, her own career, and what she remembered of the other women.

Ellen Dorrit Hoffleit

Dorrit Hoffleit was interviewed on November 11, 1976, at Yale University in New Haven, Conn. Also an early graduate student, she got her Ph.D. from Harvard in 1938. She had wonderful stories to tell about the earlier women whom she had known, and discussed how much the director, Shapley, had encouraged her in her career. This interview is preserved on tape.

Margaret Harwood

Margaret Harwood was interviewed on December 1, 1976, in her home in Cambridge, Mass. A graduate of Radcliffe, class of 1907, she worked at Harvard from 1907 to 1912 and then became the director of the observatory of the Nantucket

Maria Mitchell Association in 1916. She held this position until 1957, spending a number of winters working at Harvard. In the interview she told of her own experiences at the Observatory. Her recollections are particularly valuable because she is the only woman interviewed who was at the Observatory when Pickering was director (she is now 92 years old). This interview was taped.

Margaret Walton Mayall

Margaret Mayall was interviewed on December 8, 1976, in Cambridge, Mass. She is a graduate of Swarthmore College and worked at Harvard from 1924-43 and 1946-54. Because she was for many years Annie Cannon's chief assistant she was able to tell me much about Cannon, and also about her own career. This interview was also taped.

Cecilia Payne-Gaposchkin

Cecilia Payne-Gaposchkin has given me help with this thesis on a number of occasions. I interviewed her formally on March 7, 1977, after she had read my first draft of the chapter on the scientific work of the women at Harvard, and she was able to give me valuable information about areas which she felt I had not given enough attention. This interview is preserved on tape. She also kindly allowed me to read a few chapters of her unpublished autobiography, and to quote from it. In addition, I read the transcript of an interview with Dr. Payne-Gaposchkin conducted by Owen Gingerich on

March 5, 1968, in Cambridge, Mass. This transcript is preserved in the Niels Bohr Library of the American Institute of Physics, in New York, N.Y.

Books

Bailey, Solon I. The History and Work of Harvard Observatory 1839-1927. Harvard College Observatory Monographs no. 4. New York: McGraw-Hill Book Co., 1931. W: Educ U 4810.604.10.

A useful but somewhat dull book. Contains a complete staff list for 1839 to 1927, which has been very useful.

Berendzen, Richard, Hart, Richard, and Seeley, Daniel. Man Discovers the Galaxies. New York: Science History Publications, a division of Neale Watson Academic Publications, 1976. Wo: QB 32.B47.1976.

An interesting semi-popular account of developments in astronomy in the early 20th century. Despite somewhat confusing organization it gives a broad picture of the role of the people and the institutions in the scientific developments.

Boss, Benjamin. History of the Dudley Observatory 1852-1956. Albany, N.Y.: The Dudley Observatory, 1968. W: Astr 479.68.5.

Not a scholarly history, but useful for its staff list and for comparison with Harvard College Observatory.

Cattell, J. McKeen, ed. American Men of Science: A Biographical Directory. 2nd edition. New York: The Science Press, 1910. W: S120.15.5.

A useful reference work for the careers of moderately well-known astronomers. An interesting but limited source of data for study of the careers of women scientists.

Frost, Edwin Brant. An Astronomer's Life. Boston: Houghton Mifflin Co., 1933. W: Astr 130.4.5.

An enjoyable autobiography which gives a good picture of the life of an astronomer who was involved both in observatories at small colleges (Dartmouth), an in the early years of the big observatories (Yerkes).

Hall, Angelo. An Astronomer's Wife: The Biography of Angeline Hall. Baltimore: Nunn and Co., 1908. W: Astr 132.16.

Not a particularly profound book, but it gives an important glimpse into the role of women in the sort of social circles to which astronomers belonged.

Harvard College Observatory: The First Century. Cambridge, Mass.: Harvard College Observatory, 1946. Wo: QB 82.H33.
A useful, brief (94 pp.) history of the scientific work of Harvard College Observatory.

Jones, Bessie Zaban and Boyd, Lyle Gifford. The Harvard College Observatory: The First Four Directorships, 1839-1919. Cambridge, Mass.: Belknap Press of Harvard University Press, 1971. W: Astr 479.71.
An excellent history. Contains a chapter on the women at Harvard which is very carefully researched but does not attempt to draw any conclusions. More enjoyable to read than Bailey's book.

Kendall, Elaine. "Peculiar Institutions" An Informal History of the Seven Sister Colleges. New York: G. P. Putnam's Sons, 1975. W: Wid-LC LC 1756.K45.1975.
So informal that it gives little coherent history, but an interesting source of ideas and approaches.

Kendall, Phebe Mitchell. Maria Mitchell: Life, Letters, and Journals. Boston: Lee and Shepard Publishers, 1896. W: Astr 137.7.
A very useful compilation of primary source material with a connecting narrative. In many ways more interesting than a biography.

Kohlstedt, Sally Gregory. The Formation of the American Scientific Community: The American Association for the Advancement of Science 1848-1860. Urbana, Ill.: University of Illinois Press, 1976.
This looks like a very interesting book, but unfortunately I did not have time to do more than look up the position of women in the AAAS.

Miller, Howard S. Dollars for Research: Science and Its Patrons in Nineteenth-Century America. Seattle: University of Washington Press, 1970. Wo: Q 180.U5.M49.
An excellent book. An original and important analysis of how financial support of science evolved in America and how the different forms of financial support affected science. This book was very influential on the approach taken in this thesis.

Newcomb, Simon. The Reminiscences of an Astronomer. Boston: Houghton Mifflin and Co.: 1903. W: Astr 138.1.5.
A fascinating autobiography of an uneducated boy who became one of the leading scientists in the United States. Useful for what it indicates about the state of astronomy at the time.

Paton, Lucy Allen. Elizabeth Cary Agassiz: A Biography. Boston: Houghton Mifflin and Co., 1919. W: Educ U 6730.103.10.
A good source for the early history of Radcliffe College, of which Elizabeth Agassiz was the first president. Includes a commencement address which talks about the opportunities for women in astronomy (pp. 361-65). An enjoyable book.

Payne[-Gaposchkin], Cecilia H. The Stars of High Luminosity. Harvard Observatory Monograph no. 3. New York: McGraw Hill Book Co., 1930. W: Astr 6809.30.3.
Discusses the importance of Antonia Maury's two dimensional spectral classification system as part of the background for original scientific work.

Pickering, Edward Charles. A Plan for Securing Observations of the Variable Stars. Cambridge, Mass.: John Wilson, University Press, 1882. W: Astr 6858.82.
An interesting pamphlet because the plan described includes the encouragement of women amateurs.

Sochen, June. Herstory: A Woman's View of American History. New York: Alfred Publishing Co., 1974. W: Wid-LC HQ 1410.S64.
Little discussion of the role of women in academics and professional occupations, but some interesting ideas.

Struve, Otto and Zebergs, Velta. Astronomy of the 20th Century. New York: Macmillan Co., 1962. Wo: QB 32.S8.
A careful if somewhat whiggish history which has a good account of the importance of the work done by the women at Harvard.

U.S. Bureau of Labor Statistics. Summary of the Report on Condition of Woman and Child Wage Earners in the United States. Washington, D.C.: Government Printing Office, 1916. W: Soc 1770.22.5.
Used only for information on typical wages for women in factory work.

U.S. Bureau of the Census. Statistics of Women at Work. Based on the 12th census, 1900. Washington, D.C.: Government Printing Office, 1907. W: US Doc 159.00.25.
Used only for information on the percentage of women in various occupations.

Wright, Helen. Explorer of the Universe: A Biography of George Ellery Hale. New York: E. P. Dutton and Co., 1966. Wo: QB 36.H14.W7.
A thorough biography of the man who led the growth of the large observatories. Useful background reading, but short on description of his scientific work.

_____. Sweeper in the Sky: The Life of Maria Mitchell, First Woman Astronomer in America. New York: Macmillan Co., 1950. W: Astr 137.7.5.
A biography in the inspirational style, but well done none the less, and a useful source of reliable information on Maria Mitchell.

Journals

The journals listed below were examined to find papers written by women. The three main American journals at the time were the Astrophysical Journal, the Astronomical Journal, and Popular Astronomy. The Astrophysical Journal was the most prestigious, Popular Astronomy the least because it published both amateur and professional articles. In addition to these three there was the shorter-lived Sidereal Messenger, which changed its name to Astronomy and Astrophysics, and the American Journal of Science. The most prestigious Continental journal was the German Astronomische Nachrichten.

Astronomical Journal. Edited by B. A. Gould, 1849-1896 (not published 1861-1886), Seth Chandler, 1896-1908, Benjamin Boss, 1908-1942. 33 volumes were published between 1849 and 1921, each covering about 1 1/2 years. Wo: Journals.

Astronomiche Nachrichten. In 1875 volume 85 was being published, edited by C. A. F. Peters, who continued to edit it until 1881. Edited by H. Kreutz 1881-1907, by H. Koblod 1907-1938. Two volumes a year. Wo: Journals.

Astronomy and Astrophysics. Founded in 1883 as the Sidereal Messenger, edited by W. W. Payne 1883-91. Changed its name to Astronomy and Astrophysics in 1892 and edited by W. W. Payne and G. E. Hale 1892-94, then was replaced by the Astrophysical Journal. One volume a year. Wo: Journals under Sidereal Messenger.

Astrophysical Journal. Edited by G. E. Hale and James Keeler 1895-1900, by Hale alone 1901-1902, by Hale and E. B. Frost 1902-1912, and by Hale, Frost, and Henry G. Gale 1912-1932. Two volumes a year starting with volume 1 in 1895. Wo: Journals.

Popular Astronomy. Edited by W. W. Payne and Charlotte R. Willard 1893-1896, by Payne and H. C. Wilson 1896-1910, by Wilson alone 1911-1919, and by Wilson, Curvin H. Gingrich, and Edward A. Fath 1920-26. First six volumes published somewhat irregularly from 1893 to 1898, after than volumes are annual. Wo: Journals.

Annals of the Harvard College Observatory. Published irregularly, vol. 8 in 1896, vol. 95 in 1920. Harvard College Observatory also published results in the form of Circulars and Bulletins which are collected and bound in the Observatory Library. Wo: HCO.

Publications of the Vassar College Observatory. No. 1, 1900; No. 2, 1905; No. 3, 1913. Wo: AI 2455.

Articles

Before 1920

Byrd, Mary E. "Anna Winlock." Popular Astronomy 12 (1904): 254-58.
An interesting source of information about one of the early women at Harvard who did not become famous.

Cannon, Annie J. "Edward Charles Pickering." Popular Astronomy 27 (1919):177-83.

_____. "Williamina Paton Fleming." Astrophysical Journal 33 (1911): 314-17.
A good source for Fleming's accomplishments and honors.

Fleming, W. P. "A Field for Women's Work in Astronomy." Astronomy and Astrophysics 12 (1893): 683-89.
Interesting as a source for how Fleming felt about the developing role for women in astronomy and what she saw that role to be.

Klumpke, Dorothea. "La Femme Dans L'Astronomie." Bulletin de la Societe Astronomique de France 13 (1899): 162-70, 206-15. Wo: Journals.
The information given is often frustratingly little but still a good source for what a variety of women were doing at the time. Includes information on European women astronomers and women astronomers before the 19th century.

McKenney, Anne P. "What Women Have Done For Astronomy in the United States." Popular Astronomy 12 (1904): 171-82.
The introduction of this article appears to be plagiarized from W. P. Fleming's 1893 article listed above. Useful material on a large number of women.

Maria Mitchell. "The Collegiate Education of Girls." In Women and the Higher Education. Ed. Anna C. Brackett. New York: Harper and Brothers, 1893. W: Educ 8308.93.
Very interesting statement of her views on education for women.

_____. "Report of Miss Mitchell, Burlington, Iowa." In Reports of Observations of the Total Eclipse of the Sun, August 7, 1869. Edited by J[ohn] H[untington] C[rane] Coffin. Published by Authority of the Secretary of the Navy, [Washington, D.C., 1885]. W: Astr 1808.85.
Maria Mitchell took a group of her students on this eclipse expedition and the report includes their notes of what they saw as well as Mitchell's observations.

Reed, Helen Leah. "Women's Work at the Harvard Observatory." New England Magazine 6 (1892): 165-76. W: US 10805.10.
Interesting because a popular magazine gives a larger idea of how women astronomers were regarded at the time.

Thompson, Grace Agnes. "Williamina Paton Fleming." New England Magazine 48 (1912): 458-67. W: US 10805.10.

After 1920

Bailey, Solon I. "Henrietta Swan Leavitt." Popular Astronomy 30 (1922): 197-99.

Bok, Priscilla. "Annie Cannon, 1863-1941." Publications of the Astronomical Society of the Pacific 53 (1941): 168-70. Wo: Journals.

Boyd, Lyle G. "Mrs. Henry Draper and the Harvard College Observatory: 1883-1887." Harvard Library Bulletin 17 (1969): 70-97. W: RR 58.20.

Cambell, Leon. "Annie Jump Cannon." Popular Astronomy 49 (1941): 345-47.
The most useful of the obituaries.

Cannon, Annie J. "Sarah Frances Whiting." Popular Astronomy 35 (1927): 540-45.
Another very nice obituary.

Dictionary of Scientific Biography. S.v. "Cannon, Annie Jump," by Owen Gingerich. W: RR 5004.8.

_____. S.v. "Fleming, Williamina Paton," by Owen Gingerich.

_____. S.v. "Leavitt, Henrietta Swan," by Owen Gingerich.

_____. S.v. "Maury, Antonia Caetana de Paiva Pereira," by Owen Gingerich.

Eells, Walter Crosby. "American Doctoral Dissertations on Mathematics and Astronomy Written by Women in the Nineteenth Century." Mathematics Teacher 50 (1957): 374-76. E: Educ P 187.6.8.
There aren't many, but this article gives titles a place of publication for all that were found.

Furness, Caroline E. "Mary W. Whitney." Popular Astronomy 30 (1922): 597-608 and 31 (1923): 25-35.
A very long and complete obituary which tells lots of good stories.

Gingerich, Owen. "Laboratory Exercises in Astronomy--Spectral Classification." Sky and Telescope 28 (1964): 80-82. Wo: Journals.

Hoblit, Louse Barber. "Mary E. Byrd." Popular Astronomy 42 (1934): 496-98.

Hoffleit, Dorrit. Antonia Maury." Sky and Telescope 11 (1952): 106. Wo: Journals.

Evelyn Fox Keller. "Women in Science: An Analysis of a Social Problem." Harvard Magazine 79 (Oct. 1974): 14-19. W: HUK 137.

Makeson, Maud W. "Caroline Ellen Furness 1869-1936." Popular Astronomy 44 (1936): 233-238.
Very dependent on Furness's obituary of Whitney.

Mayall, Margaret Walton. "The Candelabrum." The Sky 5 (Jan. 1941): 3-5,14. Wo: Journals.
A particularly long and nice article about Annie Cannon.

Notable American Women 1607-1950. S.v. "Cannon, Annie Jump," by Dorrit Hoffleit. W: RR 1711.34.

_____. S.v. "Fleming, Williamina Paton Stevens," by Dorrit Hoffleit.

_____. S.v. "Whiting, Sarah Frances," by Gladys A. Anslow.

Payne-Gaposchkin, Cecilia H. "Miss Cannon and Stellar Spectroscopy." The Telescope 8 (1941):62-3.

Rossiter, Margaret W. "Women Scientists in America Before 1920." American Scientist 62 (1974): 3-2-23. SC: Periodical Shelves.
An important study of the careers of early women scientists in America. Includes not only statistical material but also biographical material on some of the women.

Russell, H. N., Payne-Gaposchkin, Cecilia H., and Menzel, D. H. "The Classification of Stellar Spectra." The Astrophysical Journal 81 (1935): 107-18.
A review paper on progress in classification and understanding of spectra.

Shapley, Harlow. "In Memorium." The Telescope 8 (1941): 53-4. Wo: Journals.
A condensation of Shapley's memorial for Annie J. Cannon.

Todd, Mabel Loomis. "Women Astronomers at Harvard." Harvard Alumni Bulliten 29 (1927): 420-22. W: HUK 137.